UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

# A two-layer, multiple-coverage seismic refraction method with computer programs in BASIC to expedite its application

by

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# ABSTRACT

This report describes a seismic refraction procedure for determining the configuration of a shallow-depth, higher speed layer underlying a lower speed layer in an area of poor-quality first arrivals. Data are obtained with the use of 12-geophone forward and reverse spreads advanced by four geophone positions so as to obtain six first arrivals at each seismic detector. Plots of the first arrivals are critically viewed to see if the arrivals meet the triple criteria of reciprocity, parallelism, and intercept time. Once judged acceptable, arrival times are entered into a computer program to determine thickness of the upper layer and velocity of the lower layer using algorithms based on the ABC method. Four computer programs written in the BASIC language resident on the Hewlett Packard 9845B desktop computer are given:

1. ELDATA--enter, compute, plot, edit, and store elevations,
2. HRFB--enter, append, edit, and store first arrivals,
3. HRCRT--plot first arrivals, and
4. HRCOMP--compute, plot, and store results.

# INTRODUCTION

The seismic refraction procedure described in this report was developed in response to the need to conduct a survey in an area within which high ambient seismic noise and low amplitude first arrivals were observed during a previous study. The target of the survey was a landfill some of which was in an abandoned quarry and some in partially excavated glacial drift. Therefore, severe velocity variations were anticipated within the overburden and an uneven bedrock surface was expected. Under these conditions, it is necessary to take data in such a way that the acceptability of the first arrivals can be judged before they are entered into a computer program to determine thickness of the upper layer and velocity of the lower layer.

The rules upon which this selection process operates are taken directly from the work of Bengt Sjögren (1984). Application of these rules requires use of first arrivals (first breaks) obtained from multiple source points (SP's) behind and ahead of each geophone position. For sets of first arrivals to be acceptable, they must satisfy Sjögren's parallelism, reciprocity, and intercept-time criteria.

Computation of the thickness of the first layer is done with the ABC method (Sheriff, 1984) also known as the method of differences (Heiland, 1940). This extremely simple yet powerful method dates back to the late twenties when it was used by the Imperial Geophysical Experimental Survey to map gold placer channels in Australia (Edge and Laby, 1931). The velocity of the higher speed layer is obtained by a least-squares procedure confined to operate within an ABC interval.

Understanding of the procedure requires knowing how and why the source points (SP's) and geophones are deployed as they are; an understanding the ABC method--its development, assumptions, and application; and an appreciation of the data acceptance criteria. Once these fundamentals are grasped, the rest of the report becomes simply a matter of bookkeeping and plotting. To ease the task of tracing through the procedure, a sample problem is included.

Although the procedure of this report is focused on seismic refraction, upon entry of a datum elevation and an estimated datum velocity, the computing program (HRCOMP) can produce the refraction statics used in processing reflection data.

An attempt has been made to minimize geophysical jargon, but if a term escapes you, I recommend reference to the Encyclopedic Dictionary of Exploration Geophysics, second edition, compiled by Sheriff (1984). This volume contains the terminology officially adopted by the Society of Exploration Geophysicist. Rather than use valuable space in defining each term as it first occurs in this report, I have keyed the definition to Sherrif's work by use of the code (S-page); for example, when the term 'shotpoint', or its equivalent 'source point' is first used it would be followed by (S-219). This reference also shows the abbreviation SP is acceptable for source point. If additional information is needed on the triple criteria of data acceptance, or more is wanted to be known about the ABC method (in particular, its extension beyond the two-layer case), I suggest reference to Sjögren (1984).

In brief, the two-layer, multiple coverage (S-162) seismic refraction (S-203,204) procedure follows the sequence:

1. Wave tests (S-275) at selected sites,
2. Layout and elevation survey of lines--program ELDATA,
3. Data acquisition using a three-cable system,
4. Initial picking and storing of first arrivals--program HRFB,
5. Plot of first arrivals and elevation--program HRCRT,
6. Critical study of first arrival plots,
7. Adjustment of first arrivals--program HRFB, and
8. Computation of first-layer thickness and second-layer velocity with plots of results--program HRCOMP.

Computer programs (listed in the appendix) are written in the BASIC language resident on the Hewlett Packard 9845B desktop computer. All plots are made on its internal printer.

## DEPLOYMENT OF SOURCE POINTS AND GEOPHONES

Sketched in figure 1 are the traveltime curves (S-257) showing first breaks (S-93) from a plane dipping interface (S-129) with data obtained by shooting in-line offset spreads (S-230) from SP's A and B at opposite ends of the array. In this report, the spread shot from SP A is called the forward spread; that shot from SP B is called the reverse spread.

Although seemingly inconsequential, the problem of maintenance of correct bookkeeping, particularly in multiple coverage methods, is not trivial. To avoid bookkeeping problems, I identify each line by a number and its north azimuth, and along every line, each position is assigned a position number (PN). These PN's are always odd numbers. All SP's and geophones (S-110) carry their own position number. Thus, with reference to figure 1, SP B at PN 29 would be termed SP 29, and the near geophone on the forward spread would be at PN 7.

It is reasonable to ask, "Why are geophones set at odd-numbered positions?" The answer is that given a seismograph of sufficient dynamic range, the data obtained in the refraction survey also can be used as input to a multi-fold (S-96) reflection survey (not discussed in this report.) With odd-numbered geophone positions, the common midpoint (S-37) or common depth point (S-36)--abbreviated as CMP and CDP, respectively--is always an integer. For example, if the SP is at PN 1 and the geophones are at PN's 3, 5 and 7, then the CMP's would be at PN's 2, 3 and 4, respectively. Keeping locations as integers allows the PN's to be used as indices and simplifies labeling of record sections (S-215).

The position number interval (PN int) is the distance between position numbers (PN's); for example, if the distance between in-line geophones at odd-numbered PN's is 3 m, then the PN interval equals 1.5 m. Only when distances are required are the distances expressed as PN's converted to distance units. For example, in figure 1, if the PN int = 1.5 m, then the distance from PN 7 to 29 would be (29-7) x 1.5 = 33 m, and the in-line offset (S-172) from SP 1 to the detector at PN 7 would be 9 m.

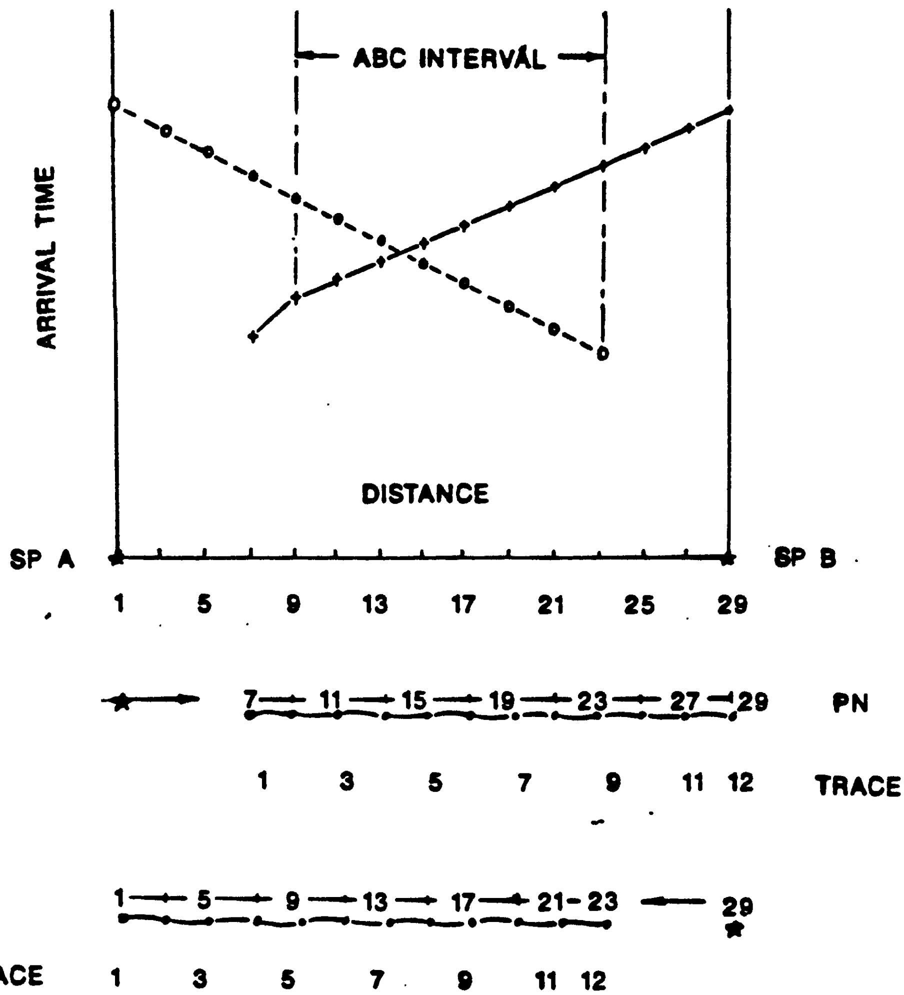



Figure 1. Traveltime curves for a plane, dipping interface. First arrival times from the forward in-line offset spread (shot from SP A) are connected with solid lines; first arrival times from the reverse in-line offset spread (shot from SP B) are connected with dashed lines. Position numbers (PN's) along the traverse from SP A to SP B are shown on the abscissa of the traveltime curve. The PN's and seismic record trace numbers for the forward spread (SP at PN 1) are shown immediately beneath the traveltime curve; PN's and seismic record trace numbers for the reverse spread (SP at PN 29) are shown beneath those of the forward spread. The ABC interval is the interval within which the ABC computing scheme (to be discussed later) can be applied.

In the procedure of this report, it is not only assumed that all surveys have been conducted along reasonably straight lines, but also that the lines have been oriented across the strike of the features. The bent-line and off-dip problems are discussed by Sjögren (1984). Briefly, for the bent-line case, the PN's rather than being scalars, become identified with a vector quantity as its index; for example, (Xn,Yn) where n is the position number. For the off-dip case (for example, the survey line does not cut across a buried channel at a right angle), rather than taking the computed normal as the normal to a line, it is to be viewed as the normal to a plane defined within a cone whose central angle equals the critical angle (S-46).

The trace (S-254) numbers on the 12-channel seismic record (S-216) for the forward (PN 7 to 29) and reverse (PN 1 to 23) spreads are shown on figure 1 beneath their respective spreads. The reciprocal time criterion requires that the refraction time from SP 1 to trace 12 on the forward-spread record equals the refraction time from SP 29 to trace 1 on the reverse-spread record. In the computing procedure, each set of reciprocal spreads carries an index, and each arrival time is doubly subscripted with use of the spread and trace numbers. For example, if the spreads on figure 1 are the fifth spread, then the reciprocal times would be Tf(5,12) and Tr(5,1) for the forward and reverse spreads, respectively.

The ABC interval shown on figure 1 is the interval within which the ABC computing scheme (to be discussed later) can be applied. For now, note that the ABC interval extends from PN 9 to 23; therefore, only refraction times on traces 2 through 9 on the forward spread and those on traces 5 through 12 on the reverse spread fall within the ABC interval. Finally, observe that if the whole array where shifted to the right such that SP A occupied the position of SP B, then ABC intervals would not overlap and thus depth determinations could not be made at all locations along the traverse beyond PN 9. However, an approximation of the depth at locations external to the ABC interval can be made by use of an assumed lower layer velocity. This approach is used in the computation procedure of this report for stations within one spread length of the beginning and end of the line.

Shown on figure 2 is an example of the traveltime curves obtained with the procedure. The first arrival times have been extracted from the suite of sample problem values. Across the bottom of the plot are the PN's and the positions of cables 1, 2, and 3. Locations of the SP's are indicated by parts of circles. First arrivals from forward spreads are connected with solid lines; those from reverse spreads are connected with dotted lines. For emphasis, the ends of the spreads are plotted with symbols--small circles for forward spreads; diamonds for the reverse spreads. To make it easier for the eye to detect the crossover distances (S-48), arrival times at the near geophones are extended back to their respective SP's with a dotted line.

Comparison of the array on figure 2 to that of figure 1 shows two significant differences:

1. A geophone is positioned at each station location, and thus the in-line offset equal one station spacing,
2. Two extra SP's are introduced between the ends of the reciprocal spreads; for example, SP's 33 and 41 between SP's 25 and 49.

It is important to observe that at stations from PN 43 to 79, six first arrivals (three from the forward and three from the reverse spreads) are plotted. This redundancy is what gives the method its power.

Returning to figure 2, notice that there are 13 station locations within each cable length. In field practice, the geophone at the SP is disconnected (made inactive); therefore, when shooting from SP 25 in the forward direction, the nearest active geophone is at PN 27, and the last geophone is at PN 49; whereas when shooting in the reverse direction from SP 49, the nearest active geophone is at PN 47. Rather than dragging the cable between each forward and reverse shot, our procedure is to use a 13-takeout (S-243) cable and a patch panel so that when shooting the forward spread, geophones are connected to takeouts 2 through 13; and when shooting the reverse spread, those geophones connected to takeouts 1 through 12 become active.

Further improvement in data acquisition productivity is gained when three cables and a patch panel are used. The patch panel serves the same function as a roll-along switch (S-211), but does so within the budget of most engineering geophysicist. A full description of the data acquisition procedure is given later in this report.

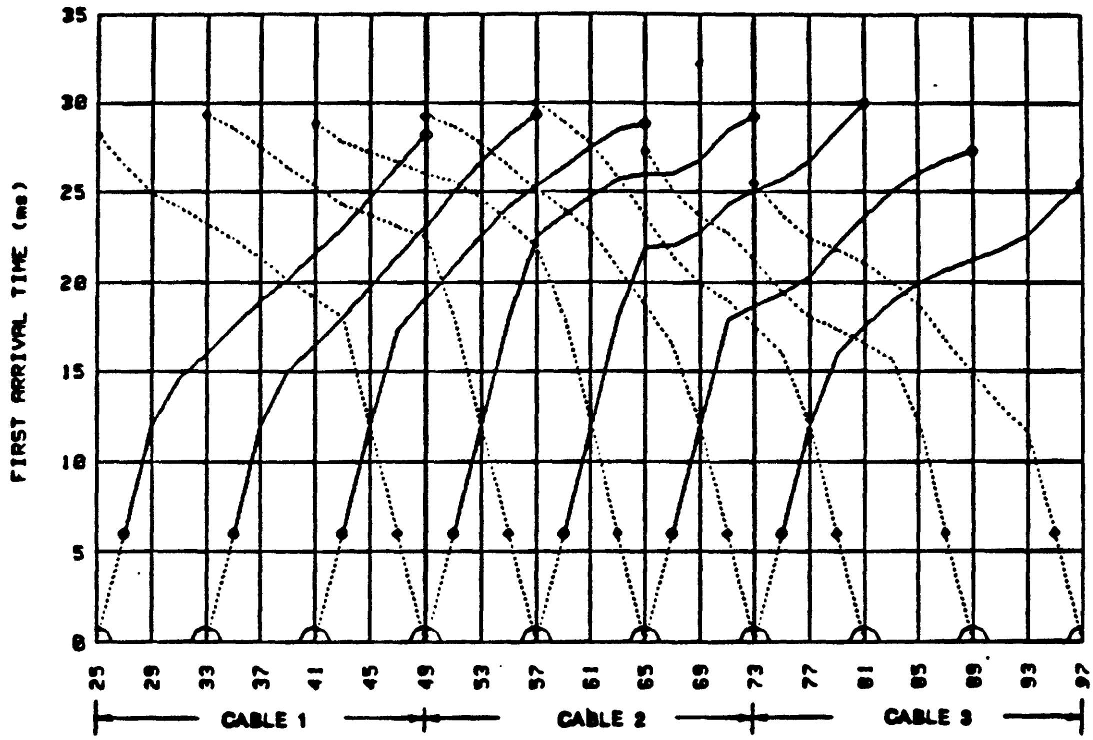



Figure 2. Example of traveltime curves produced with the multiple coverage procedure. First arrivals were produced by forward modeling of a two-layer case with variable surface elevations and thicknesses of the upper layer. First arrivals on forward spreads are connected with solid lines; those on the reverse spread are connected with dotted lines. In the usual field operation, three 13-takeout cables are deployed as shown.

The SP's and geophones were deployed as shown on figure 2 for the following reasons:

1. The project objective was limited to determination of landfill thickness. With shear-wave methods, this is essentially a two-layer case problem.

2. Results from a previous refraction survey in the area demonstrated that reliable first arrivals could not be seen much beyond 36 m even with vertical staking (S-232) using a powerful mechanical source impacting as much as 20 times. Therefore, generalized reciprocal methods, such as that of Palmer (1980), and those methods using distant in-line offsets could not be used.

3. High levels of ambient seismic noise produced at a near-by active landfill and by wind-blown high grasses over the landfill were encountered. Geophones could not be deeply buried without violating the clay cover over the landfill. Because of these high noise levels, a multiple coverage method was needed in order to utilize a procedure to evaluate data acceptability.

4. Productivity goals prohibited the use of forward and reverse shots at each station. As a compromise, a method based on the use of four SP's per cable length was selected.

## DATA ACCEPTANCE CRITERIA

The rules used to judge data acceptability are taken directly from the work of Bengt Sjögren (1984). Application of these rules requires use of first arrivals obtained from multiple source points (SP's) behind and ahead of each geophone position--a condition met by the spread deployment shown on figure 2. For sets of first arrivals to be acceptable, they must satisfy Sjögren's reciprocity, parallelism, and intercept-time criteria.

### RECIPROCITY CRITERION

The reciprocity criterion simply states that reciprocal times (S-199) must be in agreement. This is one of those statements, replete in seismics, which on the face of it seems patently obvious. With reference to figure 1, what could be more reasonable than that the time from SP A to the geophone at PN 29 must equal the time from SP 29 to the geophone at PN 1? Geometrically, this is true. And it also would be so in field practice if the seismic process were to faithfully obey mathematical rules developed on the bases of simplistic models. To quote Sportin' Life (from George Gershwin's "Porgy and Bess"): "It ain't necessarily so." Fortunately, with lower-energy P-wave (S-193) sources in a medium whose seismic properties do not significantly change laterally, the reciprocity condition holds sufficiently well. Discussion of seismic nonlinearity and lack of reciprocity with shear-wave sources is beyond the scope of this report.

Agreement of reciprocal times is an indicator of the correctness of the picked time, but it does not necessarily guarantee correctness. For example, it would be possible with low-amplitude first breaks that both the far-trace times could have been picked a whole cycle late (an effect called cycle skipping), and thus although the far-trace times would be equal, they would not be correct.

### PARALLELISM CRITERION

The parallelism criterion is also based on relatively simplistic assumptions. But, as it is with reciprocity, in many cases the assumptions hold--if not pushed too far. The basis of the parallelism criterion is illustrated in the sketch shown on figure 3. If no change in elevation were present at positions G1, G2, and G3, then the traveltime curves would be straight lines. However, with elevation changes at positions G2 and G3, the first arrivals at these stations would be delayed by an equal amount from their no-elevation-change times regardless of whether the rays originated at either SP A or SP B. Consequently, the slopes of segments on the forward-spread traveltime curves would be the same. The slopes on the reverse-spread traveltime curves also would be parallel; but only in the case of a zero-dip interface, would the slopes within the same segments be the same on the reverse spread as they are on the forward spread. Also, only in the zero-dip case would the time differences between times between those with and without a change in elevation be the same. Clearly, the magnitude of the slope and time differences over the hump in elevation is a function of the dip of the interface. Fortunately, with relatively close spaced geophones and with smooth undulations of the ground and lower layer surfaces, the slope and time differences are minor, as will be demonstrated in results shown in figure 4.

In viewing traveltime curves for parallelism, two caveats must not be ignored:

1. The refraction arrivals between successive geophones must have come from the same refracting surface. Therefore in the two-layer case, it is important that parallelism tests only be applied beyond the crossover distances.
2. The time differences for the direct-ray arrivals as functions of elevation differences will not be as much as they are with refracted arrivals. Though not shown on figure 3, imagine the time difference along a direct path from G1 to G2 with and without elevation change.

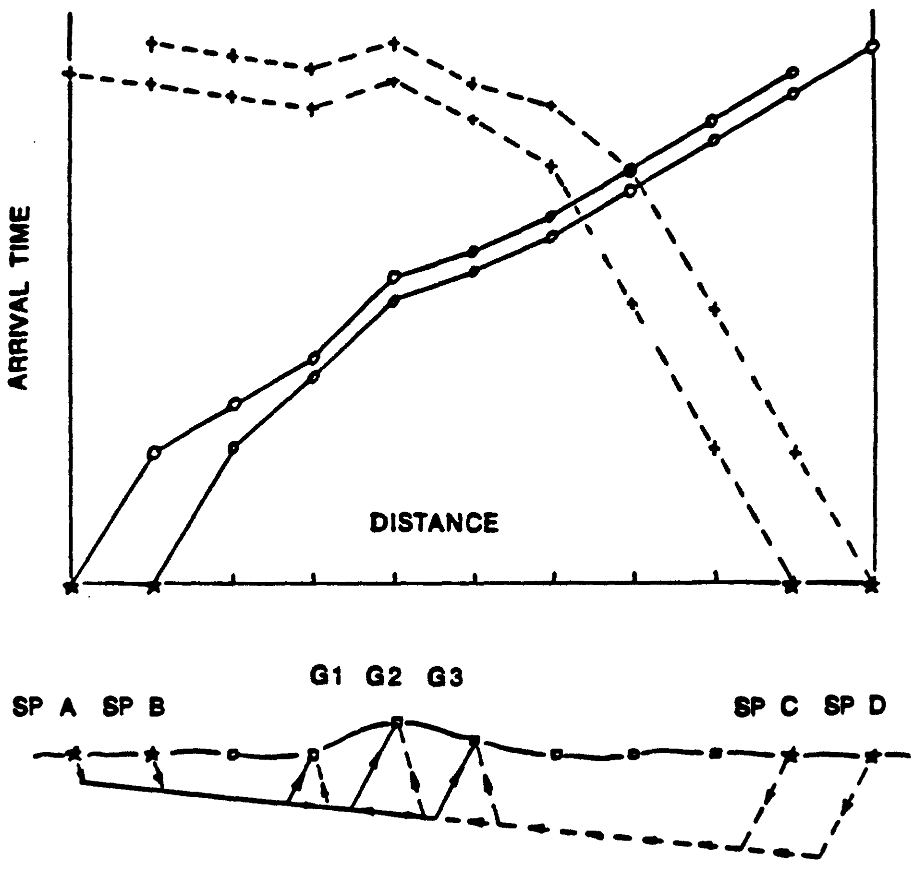



Figure 3. Sketch illustrating the parallelism criterion. Note the time delay (upward bump) on the traveltime curve at the G2 position. The basic requirement for parallelism is that the test can only be applied to successive arrivals coming from the same refracting surface; thus, the arrivals at the first and second trace arrivals from SP B do not parallel the second and third trace arrivals from SP A because the arrival from SP B to its near geophone has traveled a direct-ray path whereas other arrivals are refractions.

Shown on figure 4 is an enlargement of the segment of the traverse from PN 49 to 73 of figure 2 to illustrate parallelism and its uses as a data acceptability test and as a guide to selecting the ABC intervals. The data displayed are drawn from the sample problem.

Note in comparing figures 1 and 2, that in figure 1, only two traveltime curves are plotted, and thus if one curve showed a bump and the other did not, one would not know which value (from the forward or reverse spread) had probably been mis-timed. However, with sets of arrivals from three forward and three reverse spreads, this ambiguity would not exist.

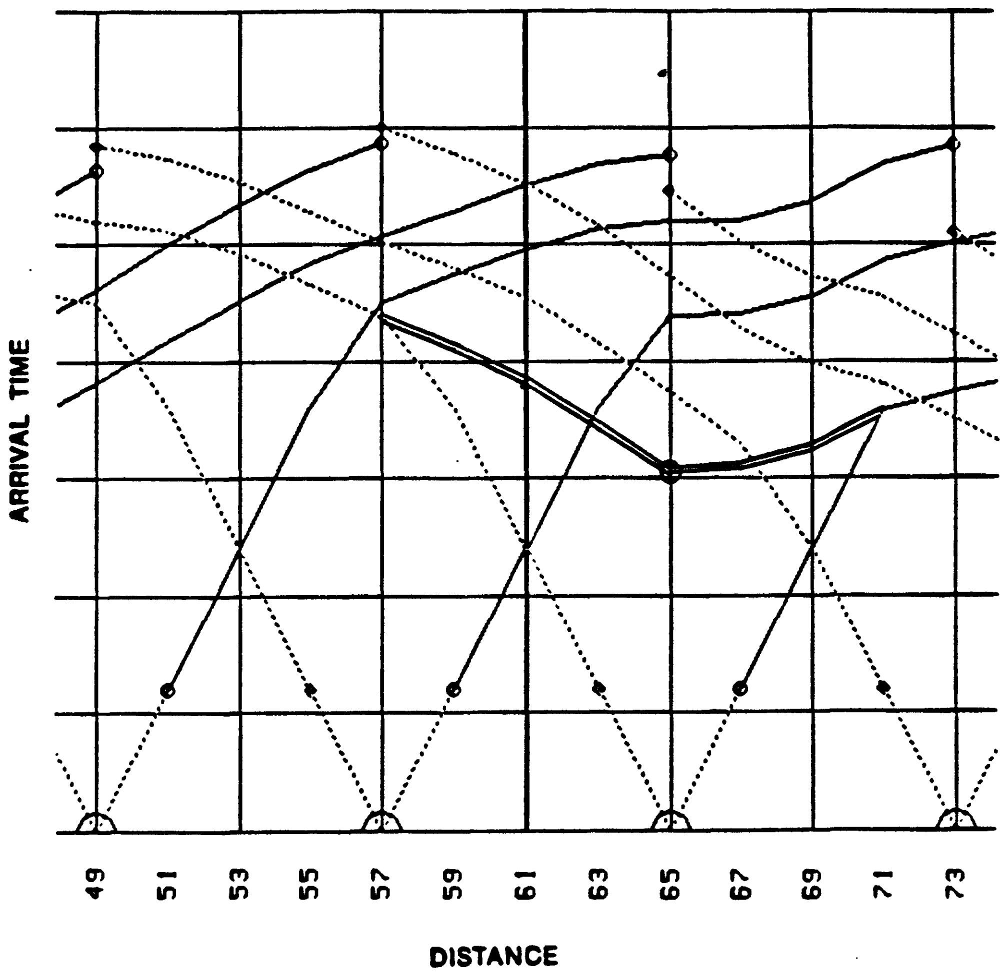



Figure 4. Enlargement of the traveltime curve of figure 2 to further illustrate the parallelism criterion and to show the graphic construction (hand drawn double lines) used to find the intercept times. The intercept time at SP 65 is circled. Note the use of parallelism in the construction.

Before the parallelism tests can be applied, it is necessary that crossover distances be determined. Referring to figures 2 or 4, for SP's 49, 57, and 65, the first geophones on the forward spreads beyond the crossover distances are located at PN's 57, 65, and 71 (traces 4, 4, and 3), respectively; whereas for SP's 57, 65, and 73, the geophones beyond the crossover distances for the reverse spreads are at PN's 49, 57, and 67 (traces 9, 9, and 10), respectively. These crossover PN's are the ones that determine the ABC intervals; for example, the ABC interval for reciprocal spreads shot from SP 49 and 73 extends from PN 57 to 67.

In the illustrative example of figure 3, the interface between the upper and lower layers was planar; however, the models used in the construction of the sample problem were not so restricted--both the ground and top of the lower layer were undulating surfaces. Therefore, all perturbations from a straight line are not solely the result of elevation changes. A good illustration of parallelism is shown in the interval from PN 65 to 73. Note that both forward and reverse spreads show a trough relative to a best-fit straight line within this interval.

## INTERCEPT TIME CRITERION

Before the intercept time criterion can be applied, the intercept times must be determined through the use of parallelism. In the ideal condition shown on figure 1, intercept times can be found simply by extrapolating the straight line connected refracted arrivals back to the zero time axis. However, with undulating surfaces introduced, another procedure is required. To find these intercept times, we again turn to the work of Sjögren (1984).

The third acceptance test is based on equality of intercept times. This tests can only be made on spreads shot backwards and forwards from the same SP. As an example of the procedure, let us determine the intercept time at SP 65, figure 4. Intercept times are determined graphically by drawing line segments in accordance with the law of parallelism (Sjögren, 1984, p. 56). Parallel rulers (such as used by navigators) are very useful in this graphical procedure. To determine the intercept time for the reverse spread, draw a line paralleling the reverse-spread refraction times from SP's 73 and 81 (see figure 2), and then draw a line paralleling the forward-spread refraction times from SP's 57 and 49. These lines have been hand-drawn as double lines on figure 4. Where they meet is the intercept time.

As long as the velocities are constant within the "ideal triangle" of Sjögren (1984, p. 59) and the ray within the high speed layer can be considered to travel along the base of the ideal triangle, the intercept time will equal twice the delay time (S-53) at the SP. If intercept times are not equal, the implication is that during the time between taking the forward and reverse record, either some change has occurred in the neighborhood of the SP (hole fatigue (S-120), for example) or within the instruments--with engineering seismograph systems, a likely malfunction being traceable to the start switch. Regardless of the cause, if the intercept and reciprocal times on one record of a set of records differ by the same amount, then all first arrival times of that record should be shifted to correct for that difference. An advantage of a 24-channel system is that with its use, the SP and instrument effects will be the same on both forward and reverse 12-trace records, and therefore, intercept times for this split spread (S-230) should agree.

The course of action upon detection of a possible mis-pick (seismic jargon for an incorrectly picked time) is to return to the original seismic record and examine that particular first arrival more closely. Usually, by comparison of the second arrivals (arrivals beyond the first arrival) on this trace with those of neighboring traces, it can be determined if the arrival time had been mis-picked. If the trace in question is particularly noisy and/or low in amplitude, the only recourse is to adjust its arrival time by shifting by an amount indicated by study of neighboring traces, and then enter the changed time in the first-break file. Provision for changing values within the first-break file is included in the HRFB program.

## SAMPLE PROBLEM

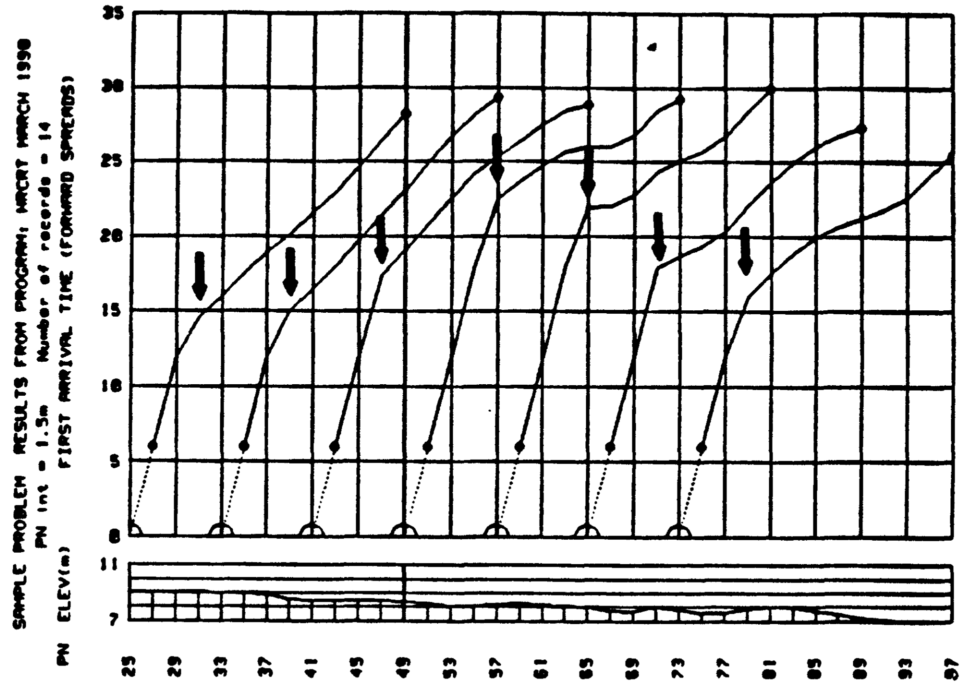
A sample problem is given in order to make the description of the data-acquisition and computing procedures easier to follow and understand. Data, tabulated in figure 5A, are presented as if they had been obtained with a 12-channel seismograph. The traverse extends from PN 1 to PN 97 (49 stations), 13 SP's are used (PN 1, 9, 17,...,97), and four cable positions are occupied. The PN interval is 1.5 m and the distance between stations is 3 m. In the forward modeling procedure, the velocity of the upper layer was 0.5 m/ms and the velocity of the lower layer was 2.5 m/ms. The sample-problem results displayed on figure 5b meet all the first-break-acceptance criteria. In field practice, considerable time and judgment are usually required to get to this point. The arrows shown on figure 5c point to geophone locations beyond the crossover distances for the last seven forward and reverse spreads of the sample problem.

```
TEST HR REFR     Line 1   Dir=0 N az   No. of record= =  20
First breaks file name: T801FB      Elevations file name: T801EL

ELEV AND FB TIMES FOR TRACES 1 THRU 12 FOR FORWARD SPREADS
For record from SP 25  at elev= 9.1 into spread from PN 27 to 49 8.9  19.0
   9.1  6.0    9.1  12.0    9.1  14.6    9.0  16.0    9.0  17.5 8.4  28.2
   8.6  20.1   8.5  21.6    8.5  23.0    8.5  24.7    8.5  26.5
For record from SP 33  at elev= 9 into spread from PN 35 to 57  8.5  19.7
   9.0  6.0    8.9  12.0    8.6  15.0    8.5  16.5    8.5  18.0 8.2  29.3
   8.5  21.4   8.4  23.1    8.3  25.0    8.1  26.7    8.1  28.2
For record from SP 41  at elev= 8.5 into spread from PN 43 to 65 8.1  22.6
   8.5  6.0    8.5  12.0    8.5  17.4    8.4  19.1    8.3  20.9 8.0  28.8
   8.1  24.2   8.2  25.3    8.3  26.4    8.2  27.5    8.1  28.4
For record from SP 49  at elev= 8.4 into spread from PN 51 to 73 8.2  24.8
   8.3  6.0    8.1  12.0    8.1  18.0    8.2  22.5    8.3  23.7 7.9  29.2
   8.1  25.7   8.0  26.0    7.8  26.0    7.7  26.8    8.0  28.4
For record from SP 57  at elev= 8.2 into spread from PN 59 to 81 7.7  22.7
   8.3  6.0    8.2  12.0    8.1  18.0    8.0  21.9    7.8  22.0 8.0  30.0
   8.0  24.3   7.9  25.1    7.6  25.7    7.6  26.7    7.9  28.4
For record from SP 65  at elev= 8 into spread from PN 67 to 89  7.6  20.3
   7.8  6.0    7.7  12.0    8.0  17.9    7.9  18.7    7.6  19.3 7.3  27.3
   7.9  22.1   8.0  23.6    8.0  25.0    7.8  26.1    7.5  26.7
For record from SP 73  at elev= 7.9 into spread from PN 75 to 97 7.8  20.0
   7.6  6.0    7.6  12.0    7.9  16.0    8.0  17.5    8.0  18.9 7.0  25.5
   7.5  20.6   7.3  21.2    7.1  21.8    7.0  22.6    7.0  24.1

ELEV AND FB TIMES FOR TRACES 1 THRU 12 FOR REVERSE SPREADS
For record from SP 49  at elev= 8.4 into spread from PN 25 to 47 9.0  22.3
   9.1  28.2   9.1  26.5    9.1  24.9    9.1  24.1    9.0  23.2 8.5   6.0
   8.9  21.3   8.6  20.1    8.5  19.1    8.5  18.0    8.5  12.0
For record from SP 57  at elev= 8.2 into spread from PN 33 to 55 8.5  24.3
   9.0  29.3   9.0  28.5    8.9  27.5    8.6  26.3    8.5  25.3 8.1   6.0
   8.5  23.7   8.5  23.1    8.4  22.5    8.3  18.0    8.1  12.0
For record from SP 65  at elev= 8 into spread from PN 41 to 63  8.3  25.6
   8.5  28.8   8.5  27.8    8.5  27.2    8.5  26.6    8.4  26.0 8.1   6.0
   8.1  24.6   8.1  23.3    8.2  21.9    8.3  18.0    8.2  12.0
For record from SP 73  at elev= 7.9 into spread from PN 49 to 71 8.3  24.0
   8.4  29.2   8.3  28.7    8.1  27.7    8.1  26.4    8.2  25.1 8.0   6.0
   8.2  22.7   8.1  20.8    8.0  18.7    7.8  16.5    7.7  12.0
For record from SP 81  at elev= 8 into spread from PN 57 to 79  7.8  21.4
   8.2  30.0   8.3  28.9    8.2  27.6    8.1  25.8    8.0  23.6 7.9   6.0
   7.7  19.9   8.0  19.0    7.9  17.5    7.6  16.0    7.6  12.0
For record from SP 89  at elev= 7.3 into spread from PN 65 to 87 7.6  19.4
   8.0  27.3   7.8  25.1    7.7  23.6    8.0  22.7    7.9  21.2 7.5   6.0
   7.6  18.0   7.9  17.4    8.0  16.6    8.0  15.7    7.8  12.0
For record from SP 97  at elev= 7 into spread from PN 73 to 95  8.0  20.0
   7.9  25.5   7.6  23.7    7.6  22.4    7.9  21.8    8.0  21.0 7.0   6.0
   7.8  18.7   7.5  16.7    7.3  14.9    7.1  13.1    7.0  11.6
```

Figure 5a. Tabulation of elevations and first arrivals for the spreads of the sample problem.



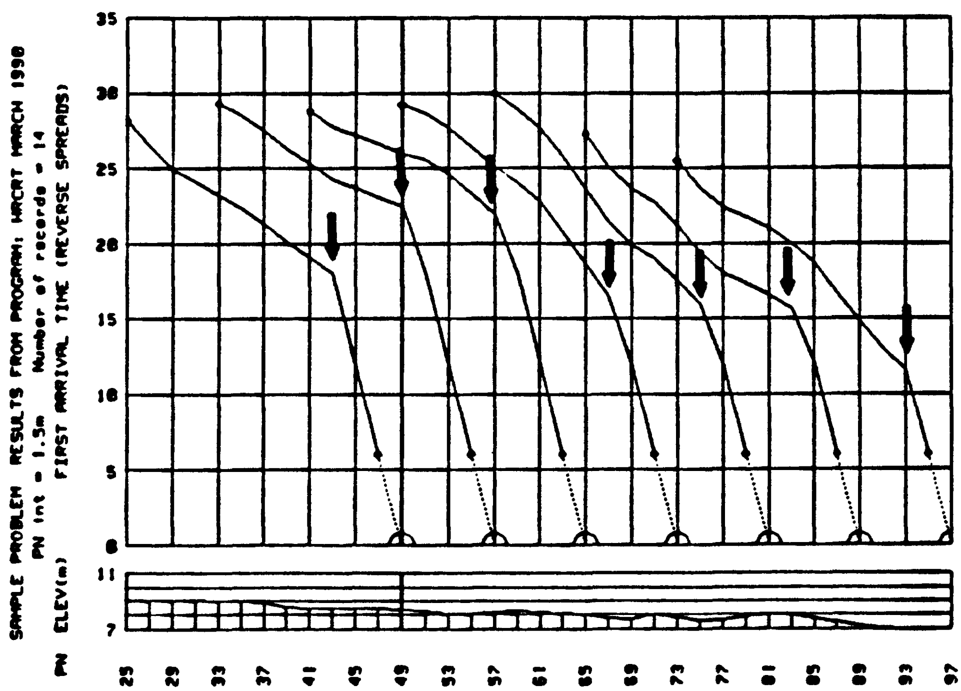




Figure 5c. Sample problem: surface elevation plot and traveltime curves for forward spread data from SP 25 to 73 (top) and for the reverse spread data from SP 49 to 97 (bottom.) Arrows point to the first geophones beyond the crossover distance.

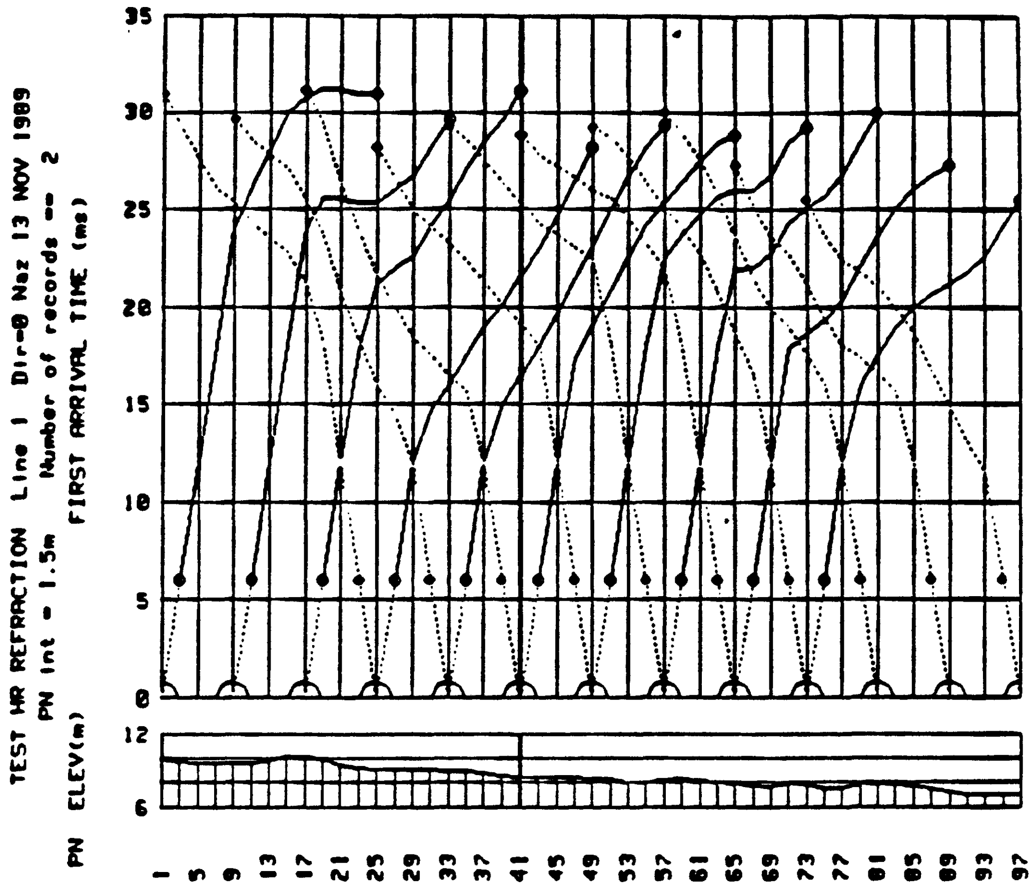



Figure 5b. Surface elevation plot and traveltime curves for first arrivals on the forward and reverse spreads of the sample problem.

## COMPUTATION OF DEPTH AND VELOCITY OF THE LOWER LAYER

The methods used to compute depth to the second layer follow directly from the basic concepts of the ABC method and the ideal triangle of Sjögren (1984) as sketched on figure 6. Looking first at the ideal triangle, observe that when V1 (velocity of the upper layer) and V2 (velocity of the refractor) remain constant in the region of the ideal triangle, the angle of the refracted ray as it leaves the refractor (the critical angle, as measured from the normal) is the same whether the ray comes in from the left or the right. Thus the triangle is isosceles, and therefore, line bd is a perpendicular bisector representing the distance from point d to the refractor. Delay time at position d is bd times the cosine of the critical angle divided by V1.

Existence conditions for the ideal triangle are that points a, b, and c are collinear and that V1 and V2 remain constant. If, for example, the base of the triangle was to span layers of different velocity, as would be the case if the vertex of the triangle was at position e on the ABC sketch (figure 6), then critical angles would not be equal, and the triangle would not be isosceles. Also, if a break in the slope of the refractor was to occur between points a and c, then the ideal triangle would no longer be formed.

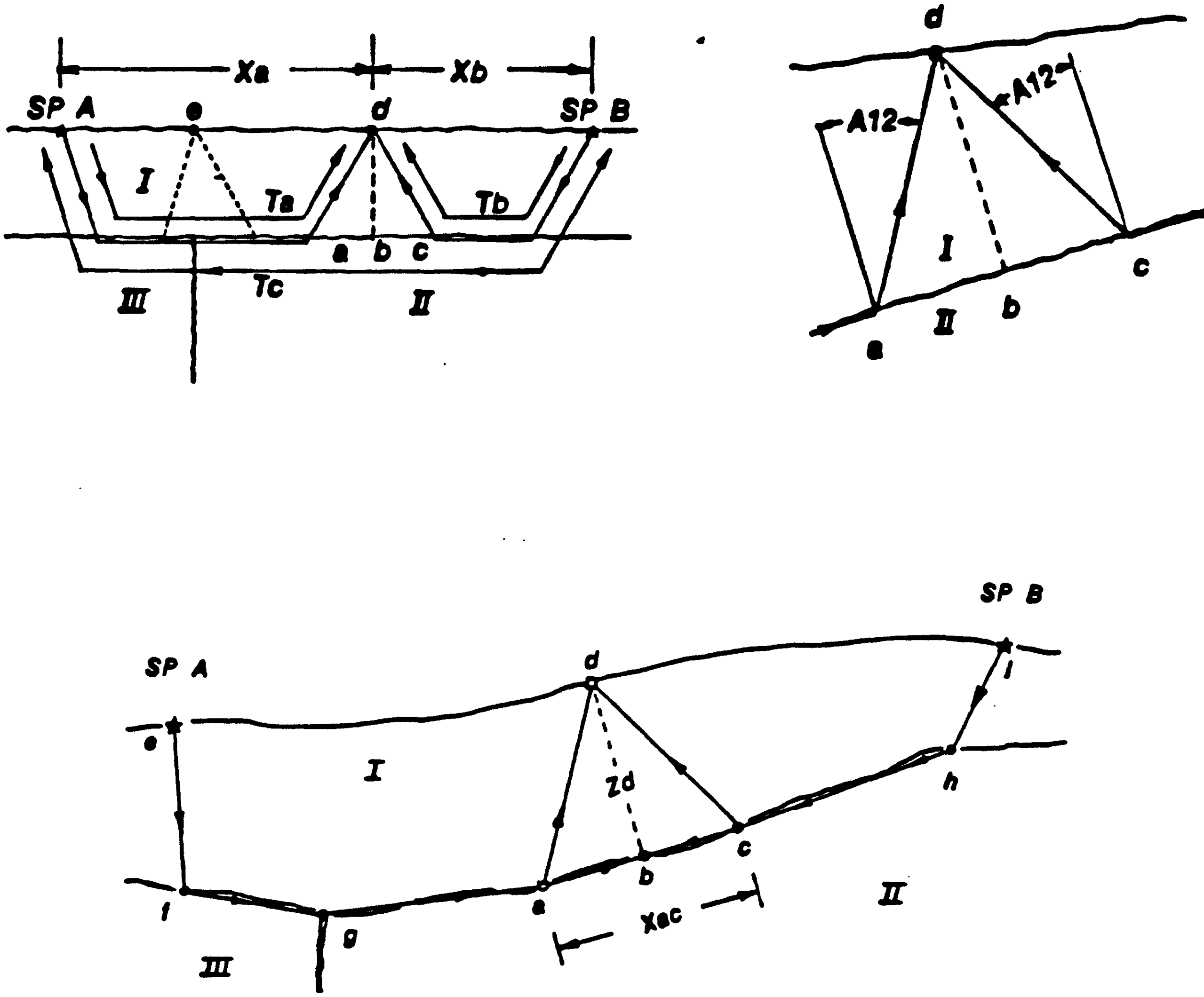



Figure 6. Sketch illustrating the concepts of the ABC method (upper left), the "ideal triangle" (upper right), and the ABC method with the ideal triangle emplaced within an uneven surface (bottom). Time Ta is the refraction time from SP A to the geophone at position d, time Tb is the refraction time from SP B to the geophone at position d, and time Tc is the reciprocal time (the refraction time from SP A to a geophone at the position of SP B). Velocity of layer III (V3) is greater than velocity of layer II (V2) which in turn is greater than that of layer I (V1). The angle A12 is the critical angle for layers I and II.

In working with computing procedures that depend on existence of the ideal triangle, consideration has to be given as to how well its conditions are approached. The greater the thickness and the smaller the velocity contrast, the greater the size of the base of the triangle, and therefore, the greater the chance that the conditions on the triangle will not be met.

To illustrate the basic concepts of the ABC method, consider on figure 6 (upper left) the following three refraction times:

Ta = time from SP A to the detector at d at an offset Xa,

Tb = time from SP B to the detector at d at an offset Xb, and

Tc = time from SP A to the geophone at the SP B location (the reciprocal time).

Letting

Da = delay time at the SP A location,

Db = delay time at the SP B location,

Dg = delay time at the station d location,

the following refraction time equations can be written:

$$Ta = Xa/f(V2,V3) + Da + Dg,$$

$$Tb = Xb/V2 + Db + Dg, \text{ and}$$

$$Tc = Xa/f(V2,V3) + Xb/V2 + Da + Db.$$

Subtracting Tc from the sum of Ta + Tb gives

$$Ta + Tb - Tc = 2 \times Dg.$$

The thickness or normal distance (Hg) from geophone to refractor is obtained from

$$Hg = Dg \times V1 / C12, \text{ where}$$

C12 = the cosine of the critical angle between layers 1 and 2, (sine of the critical angle = V1/V2).

Letting Tabc = Ta + Tb - Tc, and solving for Hg gives

$$Hg = 0.5 \times Tabc \times V1 / C12.$$

The question remains as to the conversion of normal distance to depth. Answer to this question depends on how far one wishes to extend any refraction method, and this requires consideration of many factors including the quality of the data, the nature of the ground and refractor surfaces, the orientation of the survey (was the survey on dip or strike or neither?), the validity of the numerous assumptions (for example, can discrete velocities be assumed within each layer, and if not, what velocity functions are to be used throughout the area in order to affect curved-ray solutions?), the possibility of a hidden layer (S-119) or a blind zone (S-22), the occurrence of transitional boundaries such as produced by capillarity above the static water table within the overburden, and finally, the accuracy of results required from the refraction survey--one, two, three, or more meters?

My response to the question of the meaning of the ABC depth is to consider the values obtained from delay times as representative of the distance from the apex of a cone to its base, and to bear this in mind when making the final interpretation. In effect, one can think of the results obtained as akin to those seen on an unmigrated seismic-reflection section in which events are displayed beneath the SP's, but actually may have originated up dip on the reflecting horizon or even from outside the plane of the section. Some authors (Palmer, 1980, for example) prefer on their final plots to scribe a series of circles centered at the geophone positions and then draw the refractor surface tangent to them.

The development of the ABC method given above assumed a flat ground surface and a plane refractor surface. A more realistic representation is that of an undulating ground and refractor surface. To see how the ABC method performs under this condition, let us embed the ideal triangle within an undulating surface as shown in the bottom sketch on figure 6.

The total time (Ta) from SP A to geophone d is composed of the following time segments:

$$Ta = Tef + Tfg + Tga + Tad,$$

and the time from SP B (Tb) to geophone d is

$$Tb = Tih + Thc + Tcd.$$

The total time from the SP A to SP B position in terms of time segments is

$$Tc = Tef + Tfg + Tga + Tac + Tch + Thi.$$

Letting the ABC time be symbolized by Tabc, where

$$Tabc = Ta + Tb - Tc,$$

since Tch = Thc and Thi = Tih, then

Tabc = Tad + Tcd - Tac.

Using the delay time concept, and with C12 = cos (A12), then

Tad + Tcd = 2 x Zd x C12 / V1 + Xac / V2.

Upon substitution of Tac = Xac / V2,

Tabc = 2 x Zd x C12 / V1,

which upon solution for Zd gives

Zd = 0.5 x Tabc x V1 / C12.

Note that the thickness Zd is the same as the thickness Hg computed with a flat ground surface and a zero-dip interface. The only difference is in how the thickness is interpreted, as has been previously discussed.

For computation of the thickness of the first layer near the beginning and end of the traverse (external to the coverage of the ABC intervals) the assumption is made that the velocities of the first and second layer equal those within the closest ABC interval. Once outside the confines of the ABC interval, any assumptions (such as uniformity of dip of the lower layer) can be challenged. Therefore, let us use the dictum of Occam's razor (S-171), and approach the determination of these thicknesses (depths) using the scheme sketched on figure 7.

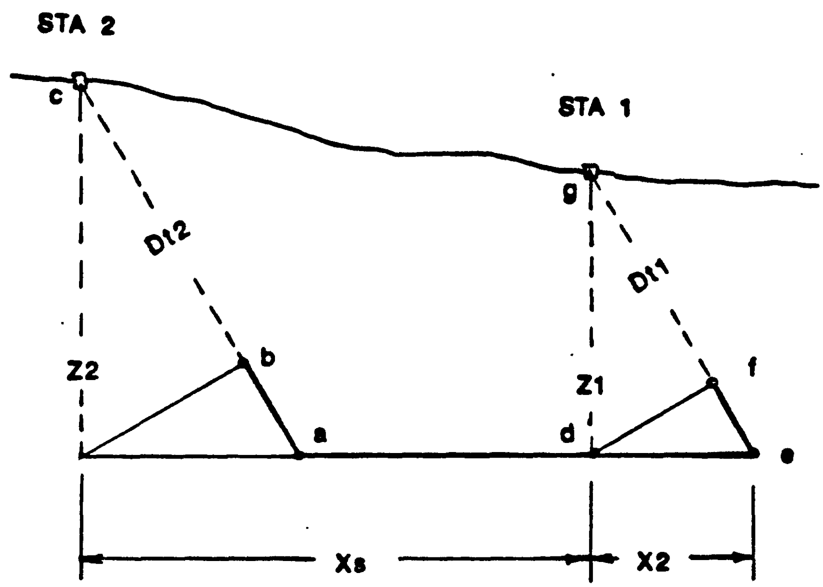



Figure 7. Sketch illustrating the quantities used in computing the thickness of the first layer at positions external to the ABC interval.

On figure 7, Dt1 and Dt2 are the delay times beneath stations 1 and 2, respectively, and Xs is the station separation. Starting from position e, let T1 be the time to STA 1, and T2 the time to STA 2. Using the delay time concept,

T2 = X2 / V2 + Xs / V2 + Dt2, and

T1 = X2 / V2 + Dt1.

The difference in arrival times at stations 2 and 1 (T21) is then

T21= Xs / V2 + Dt2 - Dt1,

which upon solution for Dt2 gives

$Dt2 = T21 - Xs / V2 + Dt1$.

With C12 being the cosine of the critical angle,

$Dt2 = Z2 \times C12 / V1$, and

$Dt1 = Z1 \times C12 / V1$.

Using the above relations, solution for Z2 gives

$Z2 = V1 \times (T21 - Xs/V2) / C12 + Z1$,

where it is understood that Z1 has been computed previously by the ABC method at the terminal position within an ABC interval.

As an example of the use of the ABC method to compute the thickness of the first layer at a given station within an ABC interval let us compute the thickness at PN 11 of the sample problem. First it is necessary to establish the times to be entered into the computing scheme. These times, and all those of the sample problem, were obtained from a forward modeling program--not included in this report. An example of those sections of that program used to compute arrival times is shown in figures 8a and 8b.

Shown on figure 8a are the model parameters for the first pair of records of the sample problem. Elevations of the surface and at the top of the second layer (base of the first layer ) are tabulated on the upper part of the figure, and a ray-trace plot at true scale is shown on the lower part of the figure. In this example, velocities within the first and second layer are constant with the values as shown.

The forward modeling program is not tied to a specific problem; therefore, station numbers rather than PN's are used. One of the uses of forward models is to generate input data to test a computation procedure. In the present application, station 1 (SP A) is at the SP 1 location, station 13 (SP B) is at the location of SP 25, and geophone PN's range from 1 to 25 at increments of two; for example, the geophone at station 6 is at PN 11. Using the trace numbering system of this report, the geophone at PN 11 would be recorded as trace 5 on the forward spread and as trace 6 on the reverse spread.

Shown on figure 8b is a tabulation of computed direct (Td) and refracted (Tr) arrival times at each station plus the offsets from respective SP's, and the traveltime curves. As labeled on these plots, first arrivals are connected with solid lines. The ABC interval (arrows shown are not part of the forward modeling program) extends from PN 11 to PN 17 (trace 5 on the forward spread; trace 9 on the reverse spread.) At Pn 11 the first arrival time from SP 1 is 26.2 ms and that from SP 25 is 24.3 ms. The SP-to-SP time, the reciprocal time, is 30.9 ms. Using these A, B, C times,

$Tabc = Ta + Tb - Tc = 19.6$ ms,

which upon substitution into the thickness equation (critical angle = 11.5 degrees) gives

$Hg = 0.5 \times 19.6 \times 0.5 / \cos(11.5) = 5.0$ m.

Throughout this report the top layer is variously referred to as the first layer (velocity = V1), the overburden, and the LVL (low velocity layer). In the literature of exploration seismics, this layer is sometimes called the weathering layer with the symbol Wx applied. Although these terms often are used interchangeably, one has to be careful to observe the context within which they have been used; for example, the overburden may not necessarily be just one layer. The layer beneath the first layer sometimes is be called the second layer (velocity = V2), bedrock, sub-LVL, or sub weathering. Again, caution is advised in assuming these terms all mean the same thing--they may not.

With the fundamentals upon which the computational parts of the procedure rests now established, let us trace through the two-layer, multiple-coverage procedure following the sequence given near the end of the introduction. Values taken from the sample problem are used in this discussion.

```
Model: SAMPLE PROBLEM  FIRST RECORD PAIR   COMPUTED: 03:20:10:59:13, 1990

STATION NUMBER, OFFSET FROM SP A, AND ELEVATIONS
```

| Sta Num | & Offset | Surface Elev | Elev at Top of Layer 2 |
|---|---|---|---|
| 1 | 0 | 10.0 | 4.6 |
| 2 | 3 | 9.8 | 4.7 |
| 3 | 6 | 9.6 | 4.7 |
| 4 | 9 | 9.6 | 4.9 |
| 5 | 12 | 9.7 | 4.8 |
| 6 | 15 | 9.6 | 4.6 |
| 7 | 18 | 9.6 | 4.5 |
| 8 | 21 | 10.2 | 4.6 |
| 9 | 24 | 10.2 | 4.8 |
| 10 | 27 | 10.0 | 5.0 |
| 11 | 30 | 9.5 | 5.1 |
| 12 | 33 | 9.3 | 5.7 |
| 13 | 36 | 9.1 | 6.1 |

TRUE SCALE PLOT OF MODEL WITH REFRACTED RAYS

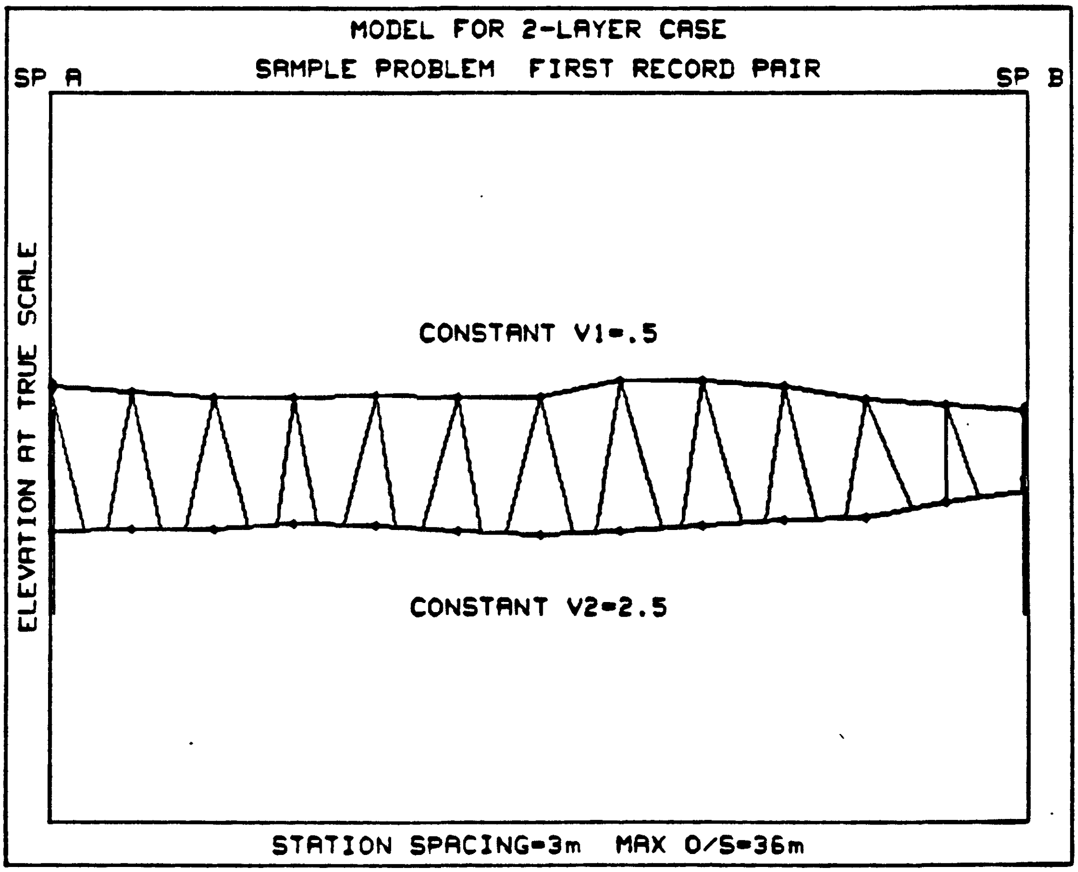



Figure 8a. Example of forward model used to compute first arrivals times for forward spread shot from SP 1 and reverse spread shot from SP 25. In the modeling program, station numbers are incremented by one, rather than by two as used in the procedure of this report. Therefore, SP B in the procedure would be at PN 25, not at station 13 as indicated in the model.

Model: SAMPLE PROBLEM FIRST RECORD PAIR COMPUTED: 03:28:18:59:43, 1990

STATION NUMBER, OFFSET, AND ARRIVALS TIMES
NOTE: Refraction time = 999 indicates no refracted return

| From SP A @ Station 1 | | | | From SP B @ Station 13 | | | |
|---|---|---|---|---|---|---|---|
| Sta Num | & Offset | Tr | Td | Sta Num | & Offset | Tr | Td |
| 1 | 0 | 999.0 | 0.0 | 1 | 36 | 30.9 | 72.3 |
| 2 | 3 | 21.8 | 6.0 | 2 | 33 | 29.2 | 66.3 |
| 3 | 6 | 22.5 | 12.0 | 3 | 30 | 27.5 | 60.2 |
| 4 | 9 | 23.4 | 18.0 | 4 | 27 | 26.1 | 54.2 |
| 5 | 12 | 24.0 | 24.0 | 5 | 24 | 25.3 | 48.2 |
| 6 | 15 | 26.2 | 30.0 | 6 | 21 | 24.3 | 42.2 |
| 7 | 18 | 27.6 | 36.0 | 7 | 18 | 23.1 | 36.2 |
| 8 | 21 | 30.0 | 42.2 | 8 | 15 | 22.8 | 30.1 |
| 9 | 24 | 30.8 | 48.2 | 9 | 12 | 21.2 | 24.1 |
| 10 | 27 | 31.2 | 54.2 | 10 | 9 | 19.3 | 18.1 |
| 11 | 30 | 31.2 | 60.2 | 11 | 6 | 16.5 | 12.0 |
| 12 | 33 | 30.9 | 66.3 | 12 | 3 | 14.8 | 6.0 |
| 13 | 36 | 30.9 | 72.3 | 13 | 0 | 999.0 | 0.0 |

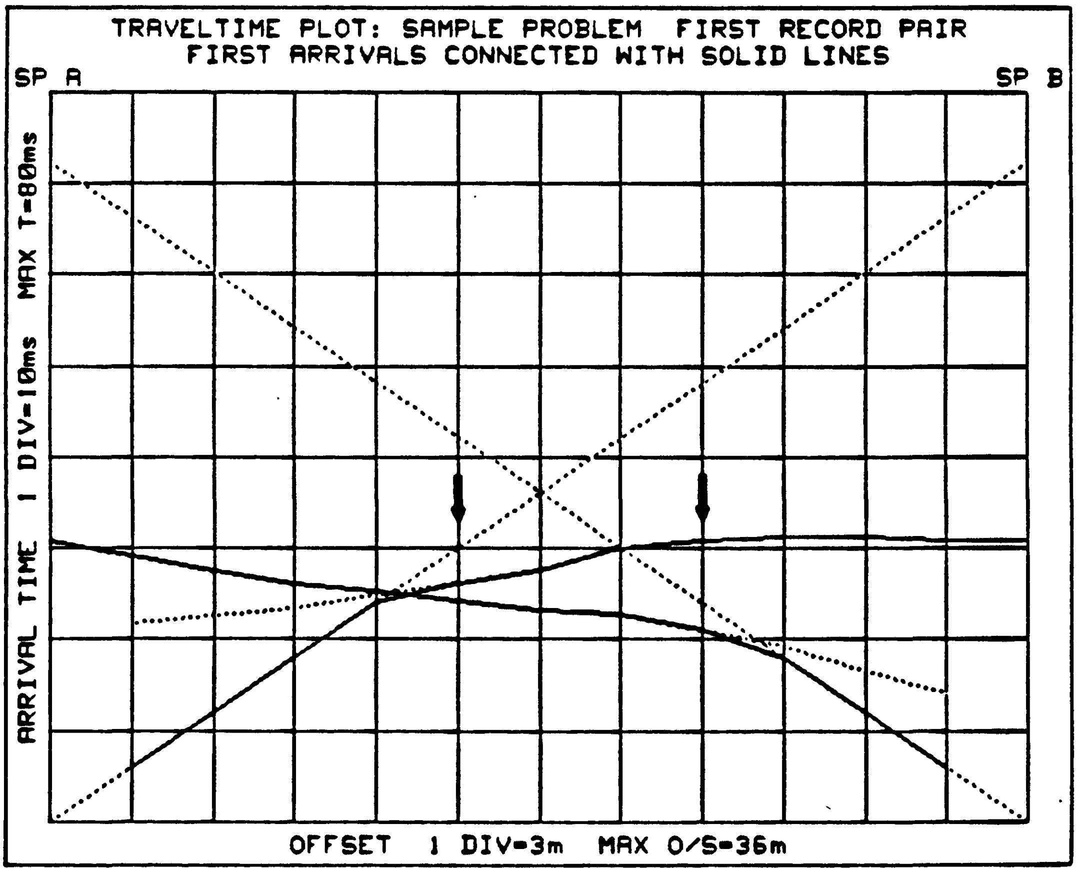



Figure 8b. Listing of direct (Td) and refracted (Tr) arrival times for the model shown in figure 8a. In constructing the traveltime curves, all arrivals are first plotted with dotted lines, following which the first arrivals are plotted with solid lines. Thus, crossover distance are easier to determine and the refraction arrival at the critical distance can be seen.

## WAVE TESTS

The procedure begins with the taking of wave tests (S-275), also called walkaways or noise tests, at locations selected to be representative of the area. The prime objective of these tests is to determine the spread length to meet the requirements of the computing procedure, namely:

1. Spreads must reach beyond the crossover distance.
2. ABC interval must be at least four groups long.
3. First arrivals at the far geophone must be from the lower layer--only a two-layer case is considered.

Wave test data also are used to evaluate the ambient seismic noise and to examine the amplitude of the first arrivals. In particular, the first arrivals at the far traces must be observable because with ABC methods reciprocal times are required.

## ACQUISITION, ENTRY, AND PLOT OF ELEVATION DATA

In areas of moderate topographic variation, traverses are laid out with the use of a long jumper cable marked at fixed intervals; thus, distances between detectors are slope distances rather than true horizontal distances. Every tenth PN is staked and clearly labeled. For example, in the sample problem, stakes would be placed at PN 1, 11, 21, ...,101.

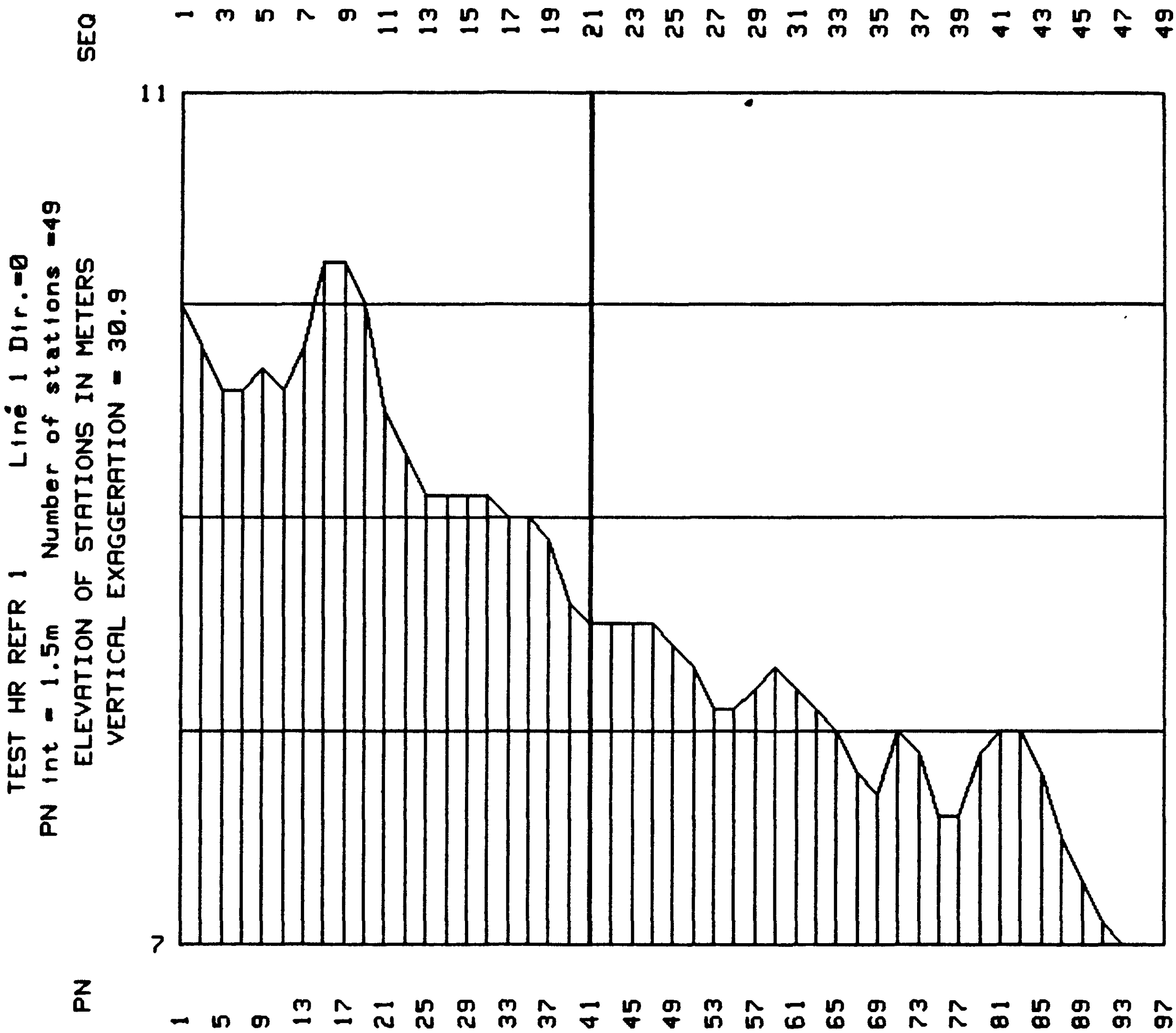
Elevations are determined with the use of a hand level and range poles alternately painted at one-feet intervals. A two-peg test is made before and after each segment of a line is surveyed. Readings are taken at each staked position (to obtain balanced foresights and backsights) and at topographic break points. Orientation of the line is determined with the use of a Brunton-type compass whose declination setting is checked by taking forward and backward readings along a road whose direction is known.

Upon entry of the survey data and information about the seismic line, the ELDATA program computes elevations at all intermediate stations and produces an elevation plot and tabulation of values such as shown on figure 9. A quick glance at the plot is usually sufficient to detect an elevation error. A corrected value of an elevation in error can be entered in the ELDATA program according to its index value shown as the SEQ number in the tabulation. Finally, a file (T801EL in the sample problem) containing the elevations is created and stored by the ELDATA program for future use in both the HRCRT and HRCOMP programs.

## DATA ACQUISITION PROCEDURE

Let us assume data are to be obtained with a 12-channel seismograph, three cables with 13 takeouts each, a patch panel with input plugs to accept the three cables, and a three-person crew. The SP and geophone PN's are to be those of the sample problem. Reference to figure 1 showing the numbering system, figure 2 showing a three-cable layout, and figure 5b showing traveltime curves for the complete sample problem may be helpful while reading through the following discussion.

While the three cables are being laid out and the geophones planted, the seismograph is set up near the first source point (SP 1) and cables #1, #2, and #3 are connected to the patch panel. Using the patch panel, the output of the geophone at PN 3 is sent to amplifier 1 (trace 1 on the seismic record), the output at PN 5 to amplifier 2, and so on for the remainder with amplifier 12 (trace 12) receiving the output of the geophone at PN 25. Let us call the record obtained from SP 1 into the spread from PN 3 to PN 25, "REC#1F"--record number 1 shot in the forward direction. After REC#1F is taken and reviewed for acceptance, the seismic source is moved to PN 9 with the spread of geophones extending from PN 11 to PN 33. With use of the patch panel, signals from geophones




TEST HR REFR 1 Line 1 Dir.=0 N az No. of sta = 49
PN interval in m = 1.5 Data file name: T801EL

| SEQ | PN | ELEV | SEQ | PN | ELEV | SEQ | PN | ELEV | SEQ | PN | ELEV |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 10.0 | 2 | 3 | 9.8 | 3 | 5 | 9.6 | 4 | 7 | 9.6 |
| 5 | 9 | 9.7 | 6 | 11 | 9.6 | 7 | 13 | 9.8 | 8 | 15 | 10.2 |
| 9 | 17 | 10.2 | 10 | 19 | 10.0 | 11 | 21 | 9.5 | 12 | 23 | 9.3 |
| 13 | 25 | 9.1 | 14 | 27 | 9.1 | 15 | 29 | 9.1 | 16 | 31 | 9.1 |
| 17 | 33 | 9.0 | 18 | 35 | 9.0 | 19 | 37 | 8.9 | 20 | 39 | 8.6 |
| 21 | 41 | 8.5 | 22 | 43 | 8.5 | 23 | 45 | 8.5 | 24 | 47 | 8.5 |
| 25 | 49 | 8.4 | 26 | 51 | 8.3 | 27 | 53 | 8.1 | 28 | 55 | 8.1 |
| 29 | 57 | 8.2 | 30 | 59 | 8.3 | 31 | 61 | 8.2 | 32 | 63 | 8.1 |
| 33 | 65 | 8.0 | 34 | 67 | 7.8 | 35 | 69 | 7.7 | 36 | 71 | 8.0 |
| 37 | 73 | 7.9 | 38 | 75 | 7.6 | 39 | 77 | 7.6 | 40 | 79 | 7.9 |
| 41 | 81 | 8.0 | 42 | 83 | 8.0 | 43 | 85 | 7.8 | 44 | 87 | 7.5 |
| 45 | 89 | 7.3 | 46 | 91 | 7.1 | 47 | 93 | 7.0 | 48 | 95 | 7.0 |
| 49 | 97 | 7.0 | | | | | | | | | |

Figure 9. Plot and tabulation of elevations produced from the ELDATA program for sample problem data stored in file: T801EL.

at PN's 11, 13, 15, 17, 19, 21, 23, and 25 (cable #1) are patched to amplifiers 1 through 8, respectively, and signals from geophones at PN's 27, 29, 31, and 33 (cable #2) are sent to amplifiers 9 through 12, respectively. This record is labeled REC#2F. The next record, REC#3F, is obtained with the source moved to PN 17 and the spread (with use of the patch panel) deployed from PN 19 to PN 41.

With the source at PN 25, two records are taken: REC#4F with a spread from PN 27 to PN 49 and record #1, reverse (REC#1R) with a spread from PN 1 to PN 23. Note that trace 12 on REC#1F is from SP 1 to the geophone at PN 25, and trace #1 on REC#1R is from SP 25 to the geophone at PN 1. Times at these particular traces are the reciprocal times.

Starting with the SP at PN 25 and ending with the SP at PN 73, data from both forward and reverse spreads are taken. The two records obtained with the SP at PN 73 are REC#10F and REC#7R. Records REC#8R, REC#9R, and REC#10R are those with SP's at PN 81, 89, and 97, respectively. Once REC#4R (SP 49) has been obtained, cable #1 (PN 1 to PN 25) can be picked up, moved, and laid out from PN 73 through PN 97. Using a 12-channel seismograph, a total of 20 records (10 single-ended-forward and 10 single-ended-reverse spreads) would be required to obtain the coverage of the sample problem.

If a 24-channel seismograph had been employed, data collection efficiency would have been markedly improved since only a total of 13 records would have had to have been taken: seven balanced split spreads (12 geophones on the reversed spread and 12 geophones on the forward spread) from SP 25 through SP 73 (the first split-spread record would be labeled REC#1S); three forward-spread records (SP's 1, 9, and 17); and three reverse-spread records (SP's 81, 89, and 97). The record from SP 1 (REC#1F)
would have used a single-ended spread from PN 3 to PN 49.

As it is with any multiple coverage seismic method, its full power is not realized near the ends of the traverse. Therefore, traverses should be chosen such that the target area lies within the area of maximum multiplicity. In the sample problem, this region lies between PN 19 and PN 79.

## ENTRY AND PLOT OF FIRST ARRIVALS

First arrivals (also called first breaks) are picked from the seismic records and then entered into the HRFB program from the keyboard. A tabulation of these values (such as that shown on figure 5a) can be called. If upon review of the tabulated
values no glaring entry errors are seen, then the HRFB program is instructed to create and store the first-breaks in a file (T801FB in the sample problem.)

The procedure of this report does not require digital recording of the seismic records. However, when forced to work with poor-quality data, it is definitely advantageous to have digitally recorded data. Not only can the seismic traces be played back at different gains, but also the records can be displayed with first arrivals vertically aligned and periodic noise reduced. Caution--automatic first-break picking programs are not recommended when signal-to-noise ratio of the first arrivals is low! The rule-of-thumb is that if picking of the first breaks requires judgment, then the eye is better than the machine.

Using the elevation and first-arrival files as input, the HRCRT program produces a plot such as shown on figure 5b. It is essential that this plot be studied carefully for from it the following can be determined:

1. First-layer velocities,
2. Approximate velocities within the second layer,
3. Crossover distances, and
4. Acceptability of first arrivals.

In calculating velocities with data from these plots it should be remembered that distances along the traverse are expressed in PN's; therefore, the PN interval must be applied to convert PN differences to length units. In the sample problem, the PN interval is 1.5 m. Velocities can be obtained graphically from the plots by drawing best-fit straight lines by eye, and then using two triangles (or a parallel ruler) translate the line to read the distance that intersects a selected time interval. On figure 10, for example, a line parallel to the first-layer arrivals crosses the 10 ms time line at a distance of 5 m, and therefore the velocity is 0.5 m/ms.

The HRCOMP program requires entry of the trace number of the first trace beyond the crossover distances for the reciprocal spreads. These trace numbers are determined from the CRT plot. Examples of this selection process are shown at the arrowed positions on figure 5c. For record 1 in the sample problem, the trace number beyond the crossover distances for the forward spread is trace 5 and the trace number beyond the crossover distance for the reverse spread is trace 9. This pair of crossover-trace numbers specifies the ABC interval for the first record pair.

## COMPUTATION AND DISPLAY OF THICKNESSES AND VELOCITIES

The HRCOMP program is used to compute the thickness of the first layer, the velocity of the refractor within the ABC interval, and the static correction for each detector on each spread. The plot produced displays on three individual panels: elevation of the surface and thickness of the upper layer, time to datum, and mean velocity along the refractor. If wanted, tabulations of thicknesses of the first layer, normal-distance times within the first-layer, approximate times to datum, static corrections, and elevation-corrected first arrivals can be printed. In addition, a two-panel plot of elevation-corrected first arrivals and surface elevations can be produced. Examples showing these tabulations and plots using data from the sample problem are given in the following section of the report.

## EXAMPLE OF HRCOMP PROGRAM USING THE SAMPLE PROBLEM

Shown on figure 10a are printouts of inputs to the HRCOMP program. File numbers on the HP 9845B are limited to six digits. Upon entry of the one-letter area designation (T), a single number for the year (8), and the line number (01), the files containing elevation and first-break information (T801EL and T801FB, respectively) are read either from the disk or from a tape. After the number of traces (detectors) per record is entered, the information on the next ten lines is printed, following which prompts are given for entry of the first-trace crossover distances.

Results produced by the HRCOMP program are shown on figure 10b (velocities), figure 10c ( LVL depths and times), 10d (combined LVL depths and times plus times to datum at each PN), and figure 10e (plot of mean V2 velocities, time to datum, elevation of the surface, and LVL thickness.) The abscissa for the plots is scaled in PN's--PN interval is given on the left side of the lower panel. Choice is given either to select the elevation of the fixed datum or let the program determine the lowest elevation along the refractor and use it as the fixed datum.

```
ENTER LEAD SYMBOLS FOR 6-CHAR FILE NAMES

 File name for first break times: T801FB
        File name for elevations: T801EL
   Number of detectors per record = 12

TEST HR REFR     Line 1   Dir=0 N az   No. of record= =  20
    Position Number (PN) interval = 1.5 m/PN
        Distance between SP pairs = 36
       Distance between detectors = 3
PN of first forward SP along line = 1
 PN of last reverse SP along line = 97
  Total number of SP's along line = 13
  Spread advance in terms of PN's = 8
Total number of detectors on line = 49
          Offset to near detector = 3 m
Number of stations to be computed = 49
TEST HR REFR     Line 1   Dir=0 N az   No. of record= =  20
Using above information, enter title wanted (72 char, max)
Title: TEST HRCOMP PROG  LINE 1 Dir=0   APRIL 10 1990
ENTER CROSSOVER DISTANCES AS PROMPTED

TRACE NO. FOR 1ST TRACE BEYOND CROSSOVER--FORWARD SPREADS
For record 1 from SP 1  trace number: 5
For record 2 from SP 9  trace number: 5
For record 3 from SP 17  trace number: 4
For record 4 from SP 25  trace number: 3
For record 5 from SP 33  trace number: 3
For record 6 from SP 41  trace number: 3
For record 7 from SP 49  trace number: 4
For record 8 from SP 57  trace number: 4
For record 9 from SP 65  trace number: 3
For record 10 from SP 73  trace number: 3

TRACE NO. FOR 1ST TRACE BEYOND CROSSOVER--REVERSE SPREADS
For record 1 from SP 25  trace number: 9
For record 2 from SP 33  trace number: 10
For record 3 from SP 41  trace number: 10
For record 4 from SP 49  trace number: 10
For record 5 from SP 57  trace number: 9
For record 6 from SP 65  trace number: 9
For record 7 from SP 73  trace number: 10
For record 8 from SP 81  trace number: 10
For record 9 from SP 89  trace number: 10
For record 10 from SP 97  trace number: 11
```

Figure 10a. Sample problem: data input to HRCOMP program. Elevation data were retrieved from file: T80EL, and first arrival data (as tabulated on figure 5a) were retrieved from file: T80FB. In response to prompts, trace numbers for first trace beyond the crossover distances for the forward and reverse spreads are entered from the keyboard (see arrowed locations on figure 5c for examples of how these trace number are determined.)

Average V1 for forward spreads = .50
Average V1 for reverse spreads = .50
Avg V1 for forward and reverse spreads = .50

ABC INTERVALS AND FIRST-LAYER VELOCITIES

| REC PAIR | FORWARD SPREADS | REVERSE SPREADS | V1abc |
|---|---|---|---|
| 1 | SP 1 TR 5 = .50 | SP 25 TR 9 = .50 | .50 |
| 2 | SP 9 TR 5 = .50 | SP 33 TR 10 = .50 | .50 |
| 3 | SP 17 TR 4 = .50 | SP 41 TR 10 = .50 | .50 |
| 4 | SP 25 TR 3 = .50 | SP 49 TR 10 = .50 | .50 |
| 5 | SP 33 TR 3 = .50 | SP 57 TR 9 = .50 | .50 |
| 6 | SP 41 TR 3 = .50 | SP 65 TR 9 = .50 | .50 |
| 7 | SP 49 TR 4 = .50 | SP 73 TR 10 = .50 | .50 |
| 8 | SP 57 TR 4 = .50 | SP 81 TR 10 = .50 | .50 |
| 9 | SP 65 TR 3 = .50 | SP 89 TR 10 = .50 | .50 |
| 10 | SP 73 TR 3 = .50 | SP 97 TR 11 = .50 | .50 |

LEAST-SQUARE APPARENT VEL WITHIN ABC INTERVALS USING OBSERVED FB'S

| Record Pair | Forward SP, | and Va | Reverse SP, | and Va | For/Rev Mean Va |
|---|---|---|---|---|---|
| 1 | 1 | 1.90 | 25 | 3.00 | 2.33 |
| 2 | 9 | 42.86 | 33 | 1.29 | 2.51 |
| 3 | 17 | 2.53 | 41 | 2.59 | 2.56 |
| 4 | 25 | 2.15 | 49 | 2.93 | 2.48 |
| 5 | 33 | 1.85 | 57 | 4.01 | 2.53 |
| 6 | 41 | 1.86 | 65 | 3.22 | 2.36 |
| 7 | 49 | 4.15 | 73 | 1.73 | 2.44 |
| 8 | 57 | 3.51 | 81 | 2.08 | 2.61 |
| 9 | 65 | 2.48 | 89 | 2.61 | 2.54 |
| 10 | 73 | 3.35 | 97 | 1.97 | 2.48 |

All-record average forward/reverse least square velocity = 2.48 m/ms

Figure 10b. Sample problem: upper layer velocities (V1) for each forward and reverse spread plus averaged values of V1; lower layer velocities (V2) within ABC intervals for each of the ten record pairs plus their mean V2 values plus all-record least-square V2 velocity as computed by the HRCOMP program using information entered as shown on figure 10a.

```
FOR DETECTORS AT BEGINNING OF LINE
SP  25 TRACE  1                    PN   1  LVL DEPTH  5.1  LVL TIME 10.2
SP  25 TRACE  2                    PN   3  LVL DEPTH  4.9  LVL TIME  9.0
SP  25 TRACE  3                    PN   5  LVL DEPTH  4.7  LVL TIME  9.3
SP  25 TRACE  4                    PN   7  LVL DEPTH  4.6  LVL TIME  9.2
SP  25 TRACE  5                    PN   9  LVL DEPTH  4.9  LVL TIME  9.7

RESULTS OF ABC COMPUTATION
Forward and Reverse SP, Record Trace, Detector PN, LVL Depth, and LVL time

SP   1 TRACE  5    SP  25 TRACE  6    PN  11  LVL DEPTH  5.0  LVL TIME 10.0
SP   1 TRACE  6    SP  25 TRACE  7    PN  13  LVL DEPTH  5.3  LVL TIME 10.5
SP   1 TRACE  7    SP  25 TRACE  8    PN  15  LVL DEPTH  5.6  LVL TIME 11.2
SP   1 TRACE  8    SP  25 TRACE  9    PN  17 .LVL DEPTH  5.4  LVL TIME 10.0

SP   9 TRACE  5    SP  33 TRACE  6    PN  19  LVL DEPTH  5.0  LVL TIME 10.0
SP   9 TRACE  6    SP  33 TRACE  7    PN  21  LVL DEPTH  4.3  LVL TIME  0.6
SP   9 TRACE  7    SP  33 TRACE  8    PN  23  LVL DEPTH  3.5  LVL TIME  7.1
SP   9 TRACE  8    SP  33 TRACE  9    PN  25  LVL DEPTH  3.0  LVL TIME  6.0
SP   9 TRACE  9    SP  33 TRACE 10    PN  27  LVL DEPTH  2.8  LVL TIME  5.6

SP  17 TRACE  4    SP  41 TRACE  5    PN  25  LVL DEPTH  3.0  LVL TIME  6.0
SP  17 TRACE  5    SP  41 TRACE  6    PN  27  LVL DEPTH  2.0  LVL TIME  5.5
SP  17 TRACE  6    SP  41 TRACE  7    PN  29  LVL DEPTH  2.5  LVL TIME  5.0
SP  17 TRACE  7    SP  41 TRACE  8    PN  31  LVL DEPTH  2.7  LVL TIME  5.4
SP  17 TRACE  8    SP  41 TRACE  9    PN  33  LVL DEPTH  2.8  LVL TIME  5.6
SP  17 TRACE  9    SP  41 TRACE 10    PN  35  LVL DEPTH  3.0  LVL TIME  6.0

SP  25 TRACE  3    SP  49 TRACE  4    PN  31  LVL DEPTH  2.7  LVL TIME  5.4
SP  25 TRACE  4    SP  49 TRACE  5    PN  33  LVL DEPTH  2.8  LVL TIME  5.6
SP  25 TRACE  5    SP  49 TRACE  6    PN  35  LVL DEPTH  3.0  LVL TIME  5.9
SP  25 TRACE  6    SP  49 TRACE  7    PN  37  LVL DEPTH  3.1  LVL TIME  6.2
SP  25 TRACE  7    SP  49 TRACE  8    PN  39  LVL DEPTH  3.1  LVL TIME  6.1
SP  25 TRACE  8    SP  49 TRACE  9    PN  41  LVL DEPTH  3.2  LVL TIME  6.4
SP  25 TRACE  9    SP  49 TRACE 10    PN  43  LVL DEPTH  3.3  LVL TIME  6.5

SP  33 TRACE  3    SP  57 TRACE  4    PN  39  LVL DEPTH  3.1  LVL TIME  6.1
SP  33 TRACE  4    SP  57 TRACE  5    PN  41  LVL DEPTH  3.2  LVL TIME  6.4
SP  33 TRACE  5    SP  57 TRACE  6    PN  43  LVL DEPTH  3.3  LVL TIME  6.6
SP  33 TRACE  6    SP  57 TRACE  7    PN  45  LVL DEPTH  3.6  LVL TIME  7.2
SP  33 TRACE  7    SP  57 TRACE  8    PN  47  LVL DEPTH  3.9  LVL TIME  7.8
SP  33 TRACE  8    SP  57 TRACE  9    PN  49  LVL DEPTH  4.2  LVL TIME  0.3

SP  41 TRACE  3    SP  65 TRACE  4    PN  47  LVL DEPTH  3.9  LVL TIME  7.0
SP  41 TRACE  4    SP  65 TRACE  5    PN  49  LVL DEPTH  4.2  LVL TIME  0.3
SP  41 TRACE  5    SP  65 TRACE  6    PN  51  LVL DEPTH  4.5  LVL TIME  9.1
SP  41 TRACE  6    SP  65 TRACE  7    PN  53  LVL DEPTH  4.7  LVL TIME  9.4
SP  41 TRACE  7    SP  65 TRACE  8    PN  55  LVL DEPTH  4.0  LVL TIME  9.6
SP  41 TRACE  8    SP  65 TRACE  9    PN  57  LVL DEPTH  4.7  LVL TIME  9.4

SP  49 TRACE  4    SP  73 TRACE  5    PN  57  LVL DEPTH  4.7  LVL TIME  9.4
SP  49 TRACE  5    SP  73 TRACE  6    PN  59  LVL DEPTH  4.7  LVL TIME  9.5
SP  49 TRACE  6    SP  73 TRACE  7    PN  61  LVL DEPTH  4.7  LVL TIME  9.3
SP  49 TRACE  7    SP  73 TRACE  8    PN  63  LVL DEPTH  4.4  LVL TIME  8.8
SP  49 TRACE  8    SP  73 TRACE  9    PN  65  LVL DEPTH  4.0  LVL TIME  7.9
SP  49 TRACE  9    SP  73 TRACE 10    PN  67  LVL DEPTH  3.4  LVL TIME  6.0

SP  57 TRACE  4    SP  81 TRACE  5    PN  65  LVL DEPTH  3.9  LVL TIME  7.9
SP  57 TRACE  5    SP  81 TRACE  6    PN  67  LVL DEPTH  3.4  LVL TIME  6.8
SP  57 TRACE  6    SP  81 TRACE  7    PN  69  LVL DEPTH  3.2  LVL TIME  6.4
SP  57 TRACE  7    SP  81 TRACE  8    PN  71  LVL DEPTH  3.4  LVL TIME  6.8
SP  57 TRACE  8    SP  81 TRACE  9    PN  73  LVL DEPTH  3.2  LVL TIME  6.4
SP  57 TRACE  9    SP  01 TRACE 10    PN  75  LVL DEPTH  3.0  LVL TIME  6.0

SP  65 TRACE  3    SP  89 TRACE  4    PN  71  LVL DEPTH  3.4  LVL TIME  6.8
SP  65 TRACE  4    SP  89 TRACE  5    PN  73  LVL DEPTH  3.2  LVL TIME  6.4
SP  65 TRACE  5    SP  89 TRACE  6    PN  75  LVL DEPTH  2.9  LVL TIME  5.8
SP  65 TRACE  6    SP  89 TRACE  7    PN  77  LVL DEPTH  2.0  LVL TIME  5.6
SP  65 TRACE  7    SP  89 TRACE  8    PN  79  LVL DEPTH  3.1  LVL TIME  6.2
SP  65 TRACE  8    SP  89 TRACE  9    PN  81  LVL DEPTH  3.3  LVL TIME  6.6
SP  65 TRACE  9    SP  89 TRACE 10    PN  83  LVL DEPTH  3.4  LVL TIME  6.8

SP  73 TRACE  3    SP  97 TRACE  4    PN  79  LVL DEPTH  3.1  LVL TIME  6.3
SP  73 TRACE  4    SP  97 TRACE  5    PN  81  LVL DEPTH  3.3  LVL TIME  6.6
SP  73 TRACE  5    SP  97 TRACE  6    PN  83  LVL DEPTH  3.4  LVL TIME  6.8
SP  73 TRACE  6    SP  97 TRACE  7    PN  85  LVL DEPTH  3.4  LVL TIME  6.7
SP  73 TRACE  7    SP  97 TRACE  8    PN  87  LVL DEPTH  3.0  LVL TIME  6.0
SP  73 TRACE  8    SP  97 TRACE  9    PN  89  LVL DEPTH  2.7  LVL TIME  5.4
SP  73 TRACE  9    SP  97 TRACE 10    PN  91  LVL DEPTH  2.4  LVL TIME  4.0
SP  73 TRACE 10    SP  97 TRACE 11    PN  93  LVL DEPTH  2.2  LVL TIME  4.4

FOR DETECTORS AT END OF LINE
SP  73 TRACE 11                    PN  95  LVL DEPTH  2.4  LVL TIME  4.7
SP  73 TRACE 12                    PN  97  LVL DEPTH  2.8  LVL TIME  4.9
```

Figure 10c. Sample problem: low velocity layer (LVL) thicknesses and times at the ends of the traverse and within ABC intervals.

LVL DEPTH, LVL TIME, AND TIME TO DATUM ALONG TRAVERSE

| Number | PN | LVL Depth | LVL Time | Time to Datum |
|---|---|---|---|---|
| 1 | 1 | 5.1 | 10.2 | 10.8 |
| 2 | 3 | 4.9 | 9.8 | 10.4 |
| 3 | 5 | 4.7 | 9.3 | 10.0 |
| 4 | 7 | 4.6 | 9.2 | 9.9 |
| 5 | 9 | 4.9 | 9.7 | 10.4 |
| 6 | 11 | 5.0 | 10.0 | 10.6 |
| 7 | 13 | 5.3 | 10.5 | 11.0 |
| 8 | 15 | 5.6 | 11.2 | 11.7 |
| 9 | 17 | 5.4 | 10.8 | 11.4 |
| 10 | 19 | 5.0 | 10.0 | 10.7 |
| 11 | 21 | 4.3 | 8.6 | 9.3 |
| 12 | 23 | 3.5 | 7.1 | 8.1 |
| 13 | 25 | 3.0 | 6.0 | 7.1 |
| 14 | 27 | 2.8 | 5.5 | 6.8 |
| 15 | 29 | 2.5 | 5.0 | 6.4 |
| 16 | 31 | 2.7 | 5.4 | 6.6 |
| 17 | 33 | 2.8 | 5.6 | 6.8 |
| 18 | 35 | 3.0 | 5.9 | 7.0 |
| 19 | 37 | 3.1 | 6.2 | 7.2 |
| 20 | 39 | 3.1 | 6.1 | 7.0 |
| 21 | 41 | 3.2 | 6.4 | 7.2 |
| 22 | 43 | 3.3 | 6.6 | 7.4 |
| 23 | 45 | 3.6 | 7.2 | 7.8 |
| 24 | 47 | 3.9 | 7.8 | 8.3 |
| 25 | 49 | 4.2 | 8.3 | 8.7 |
| 26 | 51 | 4.5 | 9.1 | 9.2 |
| 27 | 53 | 4.7 | 9.4 | 9.5 |
| 28 | 55 | 4.8 | 9.6 | 9.6 |
| 29 | 57 | 4.7 | 9.4 | 9.5 |
| 30 | 59 | 4.7 | 9.5 | 9.6 |
| 31 | 61 | 4.7 | 9.3 | 9.4 |
| 32 | 63 | 4.4 | 8.8 | 9.0 |
| 33 | 65 | 4.0 | 7.9 | 8.2 |
| 34 | 67 | 3.4 | 6.8 | 7.3 |
| 35 | 69 | 3.2 | 6.4 | 6.9 |
| 36 | 71 | 3.4 | 6.8 | 7.3 |
| 37 | 73 | 3.2 | 6.4 | 7.0 |
| 38 | 75 | 2.9 | 5.9 | 6.4 |
| 39 | 77 | 2.8 | 5.6 | 6.2 |
| 40 | 79 | 3.1 | 6.3 | 6.8 |
| 41 | 81 | 3.3 | 6.6 | 7.2 |
| 42 | 83 | 3.4 | 6.8 | 7.4 |
| 43 | 85 | 3.4 | 6.7 | 7.2 |
| 44 | 87 | 3.0 | 6.0 | 6.5 |
| 45 | 89 | 2.7 | 5.4 | 5.9 |
| 46 | 91 | 2.4 | 4.8 | 5.4 |
| 47 | 93 | 2.2 | 4.4 | 5.0 |
| 48 | 95 | 2.4 | 4.7 | 5.3 |
| 49 | 97 | 2.5 | 4.9 | 5.4 |

Figure 10d. Sample problem: LVL depth and time plus time to fixed datum (elevation=3.3 m) at each station along the traverse. Although listed as depths, more properly the depths are distances along normals from the station to the lower layer and times are the one-way times along these distances divided by the upper layer velocity. No dip correction is applied to datum times.

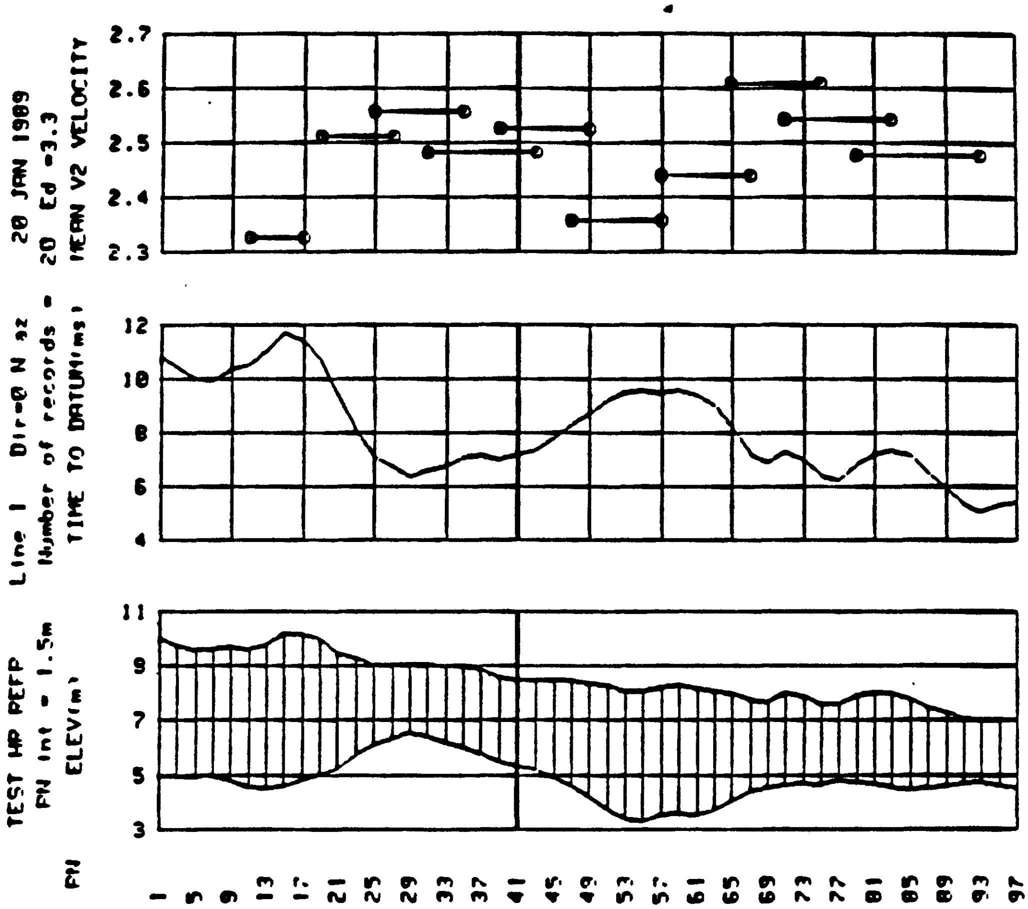



Figure 10e. Sample problem: plot of mean velocities within ABC intervals (upper panel), time to datum with elevation of datum (Ed) = 3.3 m and datum velocity equal to mean V2 (middle panel), and ground surface plus LVL thickness (lower panel). Abscissa is in PN's--with a PN interval = 1.5 m/PN, traverse distance is 144 m. Within the lower panel, vertical exaggeration is approximately 4:1, and vertical bars dropping from the surface are to be interpreted as normal distances to the refractor.

If a reflection survey is also to be made with the record set, option is provided to compute and store approximate static corrections for each record. These corrections are termed approximate since the normal thickness and times are used in their calculation rather than the true depths and vertical times to datum. This is not a serious problem since in reflection work the refraction statics are used only as first approximations. Refraction statics for the sample problem are shown on figure 11.

```
STATIC CORR FOR TRACES 1 THRU 12 FOR FORWARD SPREADS
For record 1  SP 1 into spd from PN 3 to 25
-21.3    -20.8    -20.8    -21.2    -21.4    -21.9
-22.6    -22.2    -21.5    -20.2    -18.9    -17.9
For record 2  SP 9 into spd from PN 11 to 33
-20.9    -21.4    -22.1    -21.8    -21.0    -19.7
-18.4    -17.5    -17.1    -16.7    -17.0    -17.1
For record 3  SP 17 into spd from PN 19 to 41
-22.1    -20.8    -19.5    -18.5    -18.2    -17.8
-18.0    -18.2    -18.5    -18.6    -18.4    -18.6
For record 4  SP 25 into spd from PN 27 to 49
-13.9    -13.5    -13.7    -13.9    -14.1    -14.3
-14.1    -14.3    -14.5    -14.9    -15.4    -15.8
For record 5  SP 33 into spd from PN 35 to 57
-13.8    -13.9    -13.8    -13.9    -14.1    -14.6
-15.1    -15.5    -16.0    -16.2    -16.3    -16.2
For record 6  SP 41 into spd from PN 43 to 65
-14.5    -15.0    -15.5    -15.9    -16.4    -16.6
-16.8    -16.7    -16.8    -16.6    -16.2    -15.4
For record 7  SP 49 into spd from PN 51 to 73
-18.0    -18.2    -18.3    -18.2    -18.3    -18.1
-17.7    -16.9    -16.0    -15.6    -16.0    -15.7
For record 8  SP 57 into spd from PN 59 to 81
-19.0    -18.9    -18.5    -17.7    -16.7    -16.4
-16.8    -16.5    -15.9    -15.7    -16.3    -16.7
For record 9  SP 65 into spd from PN 67 to 89
-15.5    -15.1    -15.5    -15.2    -14.6    -14.4
-15.1    -15.4    -15.6    -15.4    -14.7    -14.1
For record 10  SP 73 into spd from PN 75 to 97
-13.4    -13.2    -13.8    -14.2    -14.3    -14.2
-13.5    -12.9    -12.3    -12.0    -12.0    -12.2

STATIC CORR FOR TRACES 1 THRU 12 FOR REVERSE SPREADS
For record 1  SP 25 into spd from PN 1 to 23
-17.9    -17.5    -17.1    -17.0    -17.5    -17.7
-18.1    -18.8    -18.5    -17.8    -16.4    -15.2
For record 2  SP 33 into spd from PN 9 to 31
-17.1    -17.3    -17.8    -18.5    -18.2    -17.4
-16.1    -14.8    -13.9    -13.5    -13.1    -13.4
For record 3  SP 41 into spd from PN 17 to 39
-18.6    -17.9    -16.5    -15.3    -14.3    -13.9
-13.6    -13.8    -13.9    -14.2    -14.4    -14.2
For record 4  SP 49 into spd from PN 25 to 47
-15.8    -15.5    -15.1    -15.3    -15.5    -15.7
-15.9    -15.7    -15.9    -16.1    -16.5    -17.0
For record 5  SP 57 into spd from PN 33 to 55
-16.2    -16.5    -16.7    -16.5    -16.7    -16.8
-17.3    -17.8    -18.2    -18.7    -18.9    -19.1
For record 6  SP 65 into spd from PN 41 to 63
-15.4    -15.6    -16.0    -16.5    -16.9    -17.5
-17.7    -17.8    -17.7    -17.8    -17.6    -17.2
For record 7  SP 73 into spd from PN 49 to 71
-15.7    -16.2    -16.4    -16.6    -16.5    -16.5
-16.4    -16.0    -15.2    -14.2    -13.9    -14.3
For record 8  SP 81 into spd from PN 57 to 79
-16.7    -16.7    -16.6    -16.2    -15.4    -14.4
-14.1    -14.5    -14.2    -13.6    -13.4    -14.0
For record 9  SP 89 into spd from PN 65 to 87
-14.1    -13.2    -12.8    -13.2    -12.9    -12.4
-12.1    -12.8    -13.1    -13.3    -13.1    -12.4
For record 10  SP 97 into spd from PN 73 to 95
-12.2    -11.7    -11.4    -12.1    -12.4    -12.6
-12.4    -11.7    -11.2    -10.6    -10.3    -10.2
```

Figure 11. Sample problem: tabulation of static corrections for each trace on each forward and reverse record. First six values in a row are for traces 1 through 6; second six values (second row) are for traces 7 through 12.

The HRCOMP program also can be used to compute and apply elevation corrections to the first arrivals. A listing of elevation-corrected first breaks is shown on figures 12a (forward spreads) and 12b (reverse spreads), and a plot of these arrivals is shown on figure 12c.

```
ELEV CORRECTED FB TIMES FOR FORWARD SPREADS
For record from SP 1  at elev= 10
TRACE  ELEVATION  CORRECTED FB TIME
   5       9.6           25.9
   6       9.8           27.3
   7      10.2           28.5
   8      10.2           29.3
   9      10.0           30.1
  10       9.5           31.1
  11       9.3           31.2
  12       9.1           31.6
For record from SP 9  at elev= 9.7
TRACE  ELEVATION  CORRECTED FB TIME
   5      10.0           24.3
   6       9.5           25.3
   7       9.3           25.4
   8       9.1           25.8
   9       9.1           26.6
  10       9.1           27.2
  11       9.1           28.7
  12       9.0           30.2
For record from SP 17  at elev= 10.2
TRACE  ELEVATION  CORRECTED FB TIME
   4       9.1           19.4
   5       9.1           20.2
   6       9.1           20.8
   7       9.1           22.3
   8       9.0           23.9
   9       9.0           25.5
  10       8.9           27.1
  11       8.6           28.8
  12       8.5           30.5
For record from SP 25  at elev= 9.1
TRACE  ELEVATION  CORRECTED FB TIME
   3       9.1           13.4
   4       9.0           15.0
   5       9.0           16.5
   6       8.9           18.2
   7       8.6           19.9
   8       8.5           21.6
   9       8.5           23.0
  10       8.5           24.7
  11       8.5           26.5
  12       8.4           28.4
For record from SP 33  at elev= 9
TRACE  ELEVATION  CORRECTED FB TIME
   3       8.6           13.9
   4       8.5           15.5
   5       8.5           17.0
   6       8.5           18.7
   7       8.5           20.4
   8       8.4           22.3
   9       8.3           24.4
  10       8.1           26.5
  11       8.1           28.8
  12       8.2           28.9

For record from SP 41  at elev= 8.5
TRACE  ELEVATION  CORRECTED FB TIME
   3       8.5           16.6
   4       8.4           18.5
   5       8.3           20.4
   6       8.1           22.5
   7       8.1           24.1
   8       8.2           25.0
   9       8.3           25.9
  10       8.2           27.2
  11       8.1           28.3
  12       8.0           28.9
For record from SP 49  at elev= 8.4
TRACE  ELEVATION  CORRECTED FB TIME
   4       8.2           21.7
   5       8.3           22.7
   6       8.2           24.0
   7       8.1           25.1
   8       8.0           25.5
   9       7.8           25.9
  10       7.7           26.9
  11       8.0           27.9
  12       7.9           28.9
For record from SP 57  at elev= 8.2
TRACE  ELEVATION  CORRECTED FB TIME
   4       8.0           21.3
   5       7.8           21.8
   6       7.7           22.7
   7       8.0           23.7
   8       7.9           24.7
   9       7.6           25.9
  10       7.6           26.9
  11       7.9           28.0
  12       8.0           29.4
For record from SP 65  at elev= 8
TRACE  ELEVATION  CORRECTED FB TIME
   3       8.0           17.8
   4       7.9           18.0
   5       7.6           19.2
   6       7.6           20.2
   7       7.9           21.4
   8       8.0           22.7
   9       8.0           24.1
  10       7.8           25.6
  11       7.5           26.8
  12       7.3           27.8
For record from SP 73  at elev= 7.9
TRACE  ELEVATION  CORRECTED FB TIME
   3       7.9           14.5
   4       8.0           15.8
   5       8.0           17.2
   6       7.8           18.7
   7       7.5           19.9
   8       7.3           20.9
   9       7.1           21.9
  10       7.0           22.9
  11       7.0           24.4
  12       7.0           26.0
```

Figure 12a. Elevation-corrected first-arrival times for forward spreads of the sample problem.

ELEV CORRECTED FB TIMES FOR REVERSE SPREADS

For record from SP 25 at elev= 9.1

| TRACE | ELEVATION | CORRECTED FB TIME |
|---|---|---|
| 1 | 10.0 | 31.6 |
| 2 | 9.8 | 30.3 |
| 3 | 9.6 | 29.0 |
| 4 | 9.6 | 27.6 |
| 5 | 9.7 | 26.6 |
| 6 | 9.6 | 25.6 |
| 7 | 9.8 | 24.6 |
| 8 | 10.2 | 23.1 |
| 9 | 10.2 | 21.5 |

For record from SP 33 at elev= 9

| TRACE | ELEVATION | CORRECTED FB TIME |
|---|---|---|
| 1 | 9.7 | 30.2 |
| 2 | 9.6 | 29.3 |
| 3 | 9.8 | 28.3 |
| 4 | 16.2 | 26.8 |
| 5 | 10.2 | 25.2 |
| 6 | 10.0 | 23.7 |
| 7 | 9.5 | 21.6 |
| 8 | 9.3 | 19.6 |
| 9 | 9.1 | 17.0 |
| 10 | 9.1 | 16.2 |

For record from SP 41 at elev= 8.5

| TRACE | ELEVATION | CORRECTED FB TIME |
|---|---|---|
| 1 | 10.2 | 30.5 |
| 2 | 10.0 | 28.9 |
| 3 | 9.5 | 27.0 |
| 4 | 9.3 | 24.9 |
| 5 | 9.1 | 23.1 |
| 6 | 9.1 | 21.4 |
| 7 | 9.1 | 19.9 |
| 8 | 9.1 | 19.0 |
| 9 | 9.0 | 18.2 |
| 10 | 9.0 | 17.4 |

For record from SP 49 at elev= 8.4

| TRACE | ELEVATION | CORRECTED FB TIME |
|---|---|---|
| 1 | 9.1 | 26.4 |
| 2 | 9.1 | 26.7 |
| 3 | 9.1 | 25.1 |
| 4 | 9.1 | 24.3 |
| 5 | 9.0 | 23.6 |
| 6 | 9.0 | 22.7 |
| 7 | 8.9 | 21.9 |
| 8 | 8.6 | 21.2 |
| 9 | 8.5 | 20.4 |
| 10 | 8.5 | 19.3 |

For record from SP 57 at elev= 8.2

| TRACE | ELEVATION | CORRECTED FB TIME |
|---|---|---|
| 1 | 9.0 | 28.9 |
| 2 | 9.0 | 28.1 |
| 3 | 8.9 | 27.3 |
| 4 | 8.6 | 26.7 |
| 5 | 8.5 | 25.9 |
| 6 | 8.5 | 24.9 |
| 7 | 8.5 | 24.3 |
| 8 | 8.5 | 23.7 |
| 9 | 8.4 | 23.3 |

For record from SP 65 at elev= 8

| TRACE | ELEVATION | CORRECTED FB TIME |
|---|---|---|
| 1 | 8.5 | 28.9 |
| 2 | 8.5 | 27.9 |
| 3 | 8.5 | 27.3 |
| 4 | 8.5 | 26.7 |
| 5 | 8.4 | 26.3 |
| 6 | 8.3 | 26.1 |
| 7 | 8.1 | 25.5 |
| 8 | 8.1 | 24.2 |
| 9 | 8.2 | 22.6 |

For record from SP 73 at elev= 7.9

| TRACE | ELEVATION | CORRECTED FB TIME |
|---|---|---|
| 1 | 8.4 | 28.9 |
| 2 | 8.3 | 28.6 |
| 3 | 8.1 | 28.0 |
| 4 | 8.1 | 26.7 |
| 5 | 8.2 | 25.2 |
| 6 | 8.3 | 23.9 |
| 7 | 8.2 | 22.6 |
| 8 | 8.1 | 21.1 |
| 9 | 8.0 | 19.2 |
| 10 | 7.8 | 17.4 |

For record from SP 81 at elev= 8

| TRACE | ELEVATION | CORRECTED FB TIME |
|---|---|---|
| 1 | 8.2 | 29.4 |
| 2 | 8.3 | 28.1 |
| 3 | 8.2 | 27.0 |
| 4 | 8.1 | 25.4 |
| 5 | 8.0 | 23.4 |
| 6 | 7.8 | 21.6 |
| 7 | 7.7 | 20.3 |
| 8 | 8.0 | 18.6 |
| 9 | 7.9 | 17.5 |
| 10 | 7.6 | 16.6 |

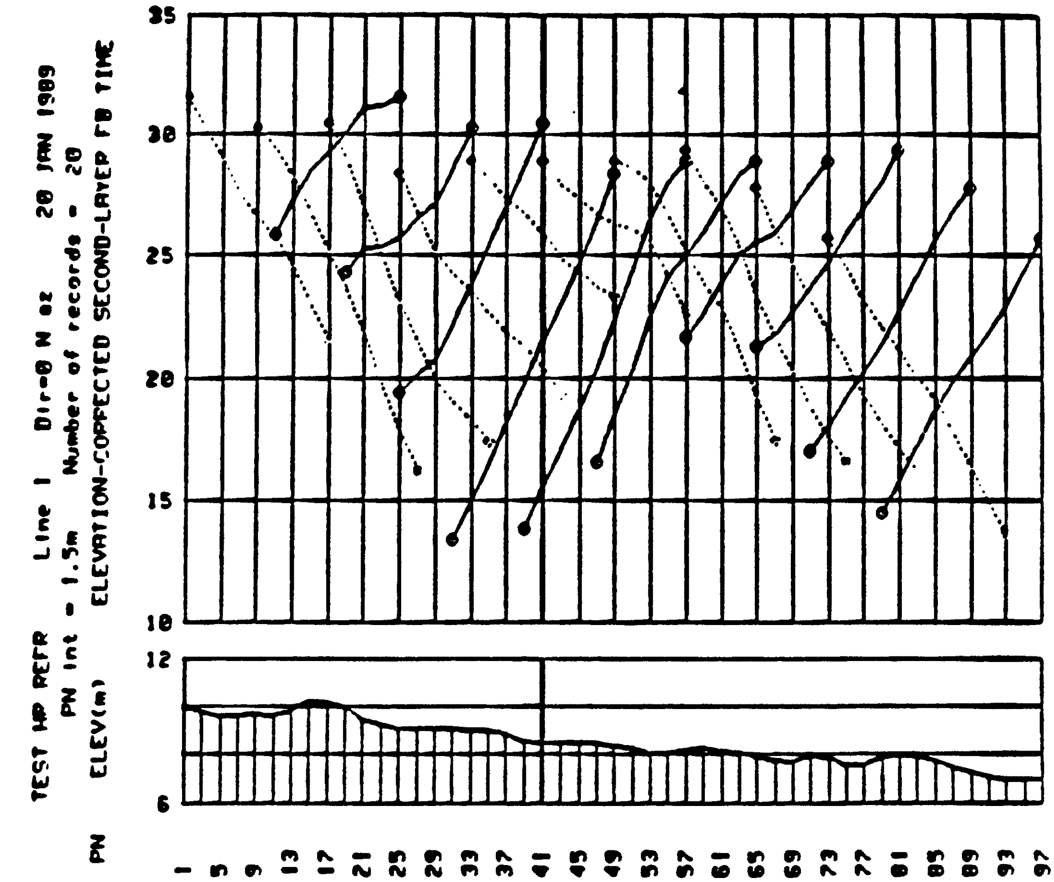
For record from SP 89 at elev= 7.3

| TRACE | ELEVATION | CORRECTED FB TIME |
|---|---|---|
| 1 | 8.0 | 27.6 |
| 2 | 7.8 | 26.0 |
| 3 | 7.7 | 24.7 |
| 4 | 8.0 | 23.2 |
| 5 | 7.9 | 21.9 |
| 6 | 7.6 | 20.7 |
| 7 | 7.6 | 19.3 |
| 8 | 7.9 | 18.1 |
| 9 | 8.8 | 17.1 |
| 10 | 8.0 | 16.2 |

For record from SP 97 at elev= 7

| TRACE | ELEVATION | CORRECTED FB TIME |
|---|---|---|
| 1 | 7.9 | 25.6 |
| 2 | 7.6 | 24.5 |
| 3 | 7.6 | 23.2 |
| 4 | 7.9 | 22.1 |
| 5 | 8.0 | 21.1 |
| 6 | 8.0 | 20.1 |
| 7 | 7.8 | 19.2 |
| 8 | 7.5 | 17.7 |
| 9 | 7.3 | 16.3 |
| 10 | 7.1 | 14.9 |
| 11 | 7.0 | 13.6 |

Figure 12b.. Elevation-corrected first-arrival times for reversed spreads of sample problem.




LEAST-SQUARE APPARENT VEL WITHIN ABC INTERVALS USING ELEV-CORRECTED FB'S

| Record Pair | Forward SP, | and Va | Reverse SP, | and Va | For/Rev Mean Va |
|---|---|---|---|---|---|
| 1 | 1 | 2.61 | 25 | 2.10 | 2.33 |
| 2 | 9 | 5.98 | 33 | 1.59 | 2.51 |
| 3 | 17 | 2.44 | 41 | 2.69 | 2.56 |
| 4 | 25 | 1.86 | 49 | 3.75 | 2.48 |
| 5 | 33 | 1.78 | 57 | 4.33 | 2.53 |
| 6 | 41 | 1.70 | 65 | 3.82 | 2.36 |
| 7 | 49 | 3.37 | 73 | 1.91 | 2.44 |
| 8 | 57 | 3.22 | 81 | 2.19 | 2.61 |
| 9 | 65 | 2.55 | 89 | 2.53 | 2.54 |
| 10 | 73 | 2.49 | 97 | 2.46 | 2.48 |

All-record average forward/reverse least square velocity = 2.48 m/ms

Figure 12c. Sample problem: traveltime curves for refraction times and tabulation of least-square velocities within ABC intervals using elevation-corrected first arrivals.

Across the bottom of figure 12c is a listing of least-square apparent and mean velocities computed with use of elevation-corrected first arrivals. A comparison between these velocities and those computed with the observed first arrivals (figure 10b) shows that although the mean least-square velocities are the same for the same record pair, the apparent least-square velocities for forward and reverse spreads within the same ABC interval are markedly different. For example, for record 2 the mean of the forward and reverse apparent velocities is 2.51 m/ms; however, the forward and reverse apparent velocities from the observed first breaks are 42.86 and 1.29 m/ms, respectively, whereas from the elevation-corrected first breaks they are 5.98 and 1.59 m/ms, respectively.

Relatively simple solution for the true dip can be made through use of apparent velocities from reversed refraction profiles. But, simple solution also requires ideal conditions, namely: a level ground surface, a uniformly dipping refractor, constant velocities, a traverse oriented on dip, and first arrivals of the highest quality. However, when working with poor-quality data taken on hilly ground over an undulating refractor and with use of a method limited to a small number of traces (those within the ABC interval), simple solutions for dip are unwarranted and therefore are not part of the method of this report.

On the elevation-corrected first-arrival plot (figure 12C) note that the equality of reciprocal times holds and that parallelism is maintained. Comparing this plot to that made with the observed data (figure 5b), observe that the traveltime curves are straighter after elevation correction, but not completely straight. This is an indication either of unevenness of the refractor surface or of changes in the layer velocities. Since in the sample problem the upper layer velocity is constant and the mean velocities of the lower layer are about the same, the cause of perturbations in the traveltime curves can be attributed to dip.

## CONCLUSIONS

The procedure described in this report was designed in response to the need to conduct a seismic refraction survey in an area of known high seismic noise and low first-arrival amplitudes. Also, it was anticipated that severe changes in the overburden velocity coupled with marked variations in both the velocity and configuration of the bedrock existed. This area presents a challenging problem, the solution for which demands development of a refraction method in which great care is taken in determining the acceptability of first arrivals before they are entered into a refraction interpretation program.

In order to ascertain first-break acceptability, field data have to be taken in such a way that arrivals at each location come from multiple source points (SP's) with the refracted rays having traveled along the same refractor. Because of the high attenuation of signals, sets of SP's at off-end positions, such as required in the GRM procedure (Palmer, 1980), could not be used. The method adopted was one in which each spread of geophones was moved by four stations and then shot from both ends of the spread.

Although it would be possible for one person to gather the data with a non-digital, single-trace seismograph and one geophone, both the physical effort and the excessive time required make this mode of operation inadvisable. Also, it would be possible to work with manually drawn plots and to perform all the calculations with the aid of a hand-held calculator. In this report, however, it is assumed that data are to be acquired with a 12- or 24- trace seismograph, a set of 13-takeout cables, and a patch panel, and that a desk-top computer is to be used. The computer programs listed and the end of this report were written in BASIC resident on the Hewlett Packard 9845B computer.

In the procedure, acceptability of the first arrivals is ascertained by application of Sjögren's rules based on equality of intercept and reciprocal times and the law of parallelism (Sjögren, 1984). Normal distances from each geophone position to the refractor are computed with the ABC method, and the mean velocity of the refractor (within a given ABC interval) is determined with the use of a least-squares procedure.

## NOTICE

Although the development of the procedure described in this report has been partially supported by the United States Environmental Protection Agency through Interagency Agreement Number DW14933103-01 to the United States Geological Survey, it has not been subjected to Agency review and therefore does not necessarily reflect the views of the Agency and no official endorsement should be inferred. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

## REFERENCES

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Palmer, Derecke, 1980, The generalized reciprocal method of refraction interpretation (ed. Kenneth B. S. Burke), Soc. Exploration Geophysicist, Tulsa, Okla.

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```
10    PRINT "ENTER, COMPUTE, PLOT, AND STORE SURVEY DATA 'ELDATA' 13 NOV 1989"
20    PRINT "Elevations are listed, plotted, and stored in meters"
30    PRINT "Distance between stations = 2 position numbers (PN)."
40    OPTION BASE 1
50    OVERLAP
60    DIM G$[1]
70    GOSUB File_name               ! Enter file name
80    GOSUB Param                   ! Enter elevation survey parameters
90    GOSUB Enter                   ! Enter elevation survey values
100   GOSUB Plot                    ! Plot elevations
110   GOSUB Tab_list                ! Tabulate elevations
120   GOSUB Corr_list               ! Correct the listing
130   GOSUB Store_elev              ! Store elevations
140   BEEP
150   DISP "PROGRAM COMPLETED"
160   END
170   !
180   DIM A$[18],B$[80],C$[80],D$[80],E$[80],Info$[80],Li$[19]
190   INTEGER L1(500),Pn(500),Seq(500)
200   SHORT Elev(500)
210   !
220 File_name:                      ! Enter file name
230   PRINT LIN(1);"ENTER SYMBOLS FOR 6-CHAR FILE NAME AS PROMPTED"
240   INPUT "One-letter area designation; ",B$
250   INPUT "Single number for year (example: 1985=5)",Y$
260   INPUT "Line number (max=99, if <10, prefix with 0);",L$
270   Na$=B$&Y$&L$
280   Elev$=Na$&"EL"
290   PRINT LIN(1);"File name for elevations: ";Elev$
300   G$="Y"
310   INPUT "Is file name correct? (Y/N--default is Y)",G$
320   IF G$="N" THEN 240
330   G$="N"
340   INPUT "Do you want to plot stored elevations? (Y/N--default is N)",G$
350   IF G$="N" THEN 390
360   Q5=1                          ! Q5=1; flag for stored data
370   GOSUB Read_elev               ! Read stored set of elevations
380   GOTO 100
390   PRINT LIN(1);"ENTER LIST TITLE INFORMATION AS PROMPTED"
400   Q5=2                          ! Q5=2; flag for entered data
410   INPUT "Area (18 char,max):",A$
420   A$=A$&"   "
430   INPUT "Line number (5 char,max):",Li$
440   Li$="   Line "&Li$
450   INPUT "Direction of line, north azimuth",Dir
460   Dir$=VAL$(Dir)
470   Pnint=1.5
480   INPUT "PN interval, expressed in m/PN (default = 1.5):",Pnint
490   INPUT "PN at beginning of line:",Pn1
500   Pn(1)=Pn1
```

```
510   INPUT "PN at end of line:",Pn2
520   NO=.5*(Pn2-Pn1)+1              ! NO=number of stations along the line
530   PRINT "Number of stations along the line =";NO
540   NO$=VAL$(NO)
550   REDIM Elev(NO),Pn(NO),Seq(NO)
560   M=0                            ! Establish sequence numbers
570   FOR J=1 TO NO
580     M=M+1
590     Seq(J)=M
600   NEXT J
610   PRINT "        Total length of the line =";2*Pnint*(NO-1)
620   Info$=A$&Li$&" Dir.="&Dir$&" N az"&"   No. of sta ="&"   "&NO$
630   RETURN
640   !
650 Param:                           ! Enter survey parameters
660   Q2=1                           ! Q2=1; flag for elev's entered in m
670   G$="Y"
680   INPUT "Are elevations to be entered in meters? (Y/N--default is Y)",G$
690   IF G$="Y" THEN 710
700   Q2=2                           ! Q2=2; flag for elev's entered in ft
710   INPUT "Assumed elevation at beginning of line:",Elev(1)
720   INPUT "True elevation at beginning of line:",E1true
730   Base=E1true-Elev(1)            ! Base elevation for computations
740   RETURN
750   !
760 Enter:                           ! Enter PN's and elevations
770   PRINT LIN(1);"ENTER PN'S AND ELEVATIONS AS PROMPTED"
780   L1(1)=1
790   FOR J=2 TO NO
800     INPUT "Next PN:",Pnum
810     L=(Pnum-Pn1)/2+1
820     L1(J)=L
830     INPUT "Next elevation: ",Elev(L)
840     Pn(L)=Pnum
850     PRINT "PN=";Pnum;"  Elev=";Elev(L)
860     N=L1(J)-L1(J-1)
870     IF N=1 THEN 950              ! Branch; no interpolated values
880     Slope=(Elev(L)-Elev(L-N))/N
890     M=L-N
900     FOR K=1 TO N-1
910       M=M+1
920       Elev(M)=K*Slope+Elev(L-N)
930       Pn(M)=K*2+Pn(L-N)
940     NEXT K
950     IF Pnum=Pn2 THEN 970
960   NEXT J
970   MAT Elev=Elev+(Base)
980   IF Q2=1 THEN 1000              ! Branch; elevations entered in meters
990   MAT Elev=Elev*(.3048)          ! Convert elev. in ft to meters
1000  RETURN
```

```
1010  !
1020 Plot:                          ! Plot elevations
1030  IF Q5=1 THEN 1070              ! Branch; plot stored elevations
1040  G$="Y"
1050  INPUT "Do you want to plot elevations? (Y/N--default is Y)",G$
1060  IF G$="N" THEN 2220
1070  PRINTER IS 16
1080  G$="Y"
1090  INPUT "Do you want to plot all elevations? (Y/N--default is Y)",G$
1100  IF G$="Y" THEN 1160
1110  INPUT "Position number at which plot is to begin:",Pnstart
1120  INPUT "Position number at which plot is to end:",Pnend
1130  J1=(Pnstart-Pn1)/2+1          ! Index of PN at start of plot
1140  J4=(Pnend-Pn1)/2+1            ! Index of PN at end of plot
1150  GOTO 1180
1160  J1=1                          ! Index of first PN for all values
1170  J4=N0                         ! Index of last PN for all values
1180  Nsta=J4-J1+1                  ! Number of stations to be plotted
1190  Nsta$=VAL$(Nsta)
1200  PRINT "Number of stations to be plotted = ";Nsta$
1210  INPUT "Number of points wanted in first panel (use odd number):",Nvp1
1220  Ns=Nvp1-1                     ! Number of spaces in first panel
1230  IF Nsta>Nvp1 THEN 1260
1240  Npan=1
1250  GOTO 1330
1260  Nvp2=2*Nvp1-1
1270  Ns2=2*Ns                      ! Number of spaces in other panels
1280  FOR P=1 TO 100
1290    Ns=Ns+Ns2
1300    IF Ns>=Nsta-1 THEN 1320
1310  NEXT P
1320  Npan=P+1
1330  PRINT "Number of panels required =";Npan
1340  Nlast=N0-(Ns-2*(Nvp1-1))
1350  PRINT "Number of values in first panel =";Nvp1
1360  PRINT " Number of values in last panel =";Nlast
1370  G$="N"
1380  INPUT "Do you want different number of values in panel 1? (Y/N--default is N)",G$
1390  IF G$="N" THEN 1410
1400  GOTO 1210
1410  Ngdu=100*Npan-50              ! Total number of GDU's for all panels
1420  Gs=Ngdu/Ns                    ! Number of GDU's per plot station space
1430  MAT SEARCH Elev(*),MAX;Max_elev    ! Find maximum elevation
1440  MAT SEARCH Elev(*),MIN;Min_elev    ! Find minimum elevation
1450  PRINT LIN(1)
1460  IMAGE "Along total line, min elev = ",4D.D," and max elev = ",4D.D
1470  PRINT USING 1460;Min_elev,Max_elev
1480  Ei=2
1490  INPUT "Elevation increment for plot (default is 2 m):",Ei
1500  Top_elev=INT(Max_elev/Ei)*Ei+Ei
```

```
1510  Bot_elev=INT(Min_elev/Ei)*Ei
1520  IF Top_elev<>Bot_elev THEN 1550
1530  Ei=Ei-1
1540  GOTO 1490
1550  Vex=(Nvp1-1)*4.124*Pnint/(Top_elev-Bot_elev)
1560  Vex=DROUND(Vex,3)
1570  Vex$=VAL$(Vex)
1580  E$="VERTICAL EXAGGERATION = "&VAL$(Vex)
1590  PRINTER IS 0
1600  DEG
1610  PRINT LIN(2)                    ! Paper advance 2 spaces before plotting
1620  PLOTTER IS 13,"GRAPHICS"
1630  GRAPHICS
1640  RESTORE
1650  DATA 0,123.1,0,100,72,50        ! Border values
1660  READ B1,B2,B4,B5,B7,B9
1670  B3=B2-B1
1680  B6=B5-B4
1690  CLIP B1,B2,B4,B7
1700  GOSUB Print_label               ! Print plot label
1710  J2=J1                           ! Initialization for J1 in 'Pan' loop
1720  Y1=B9                           ! Starting Y value for panel 1
1730  FOR Pan=1 TO Npan               ! Print PN's and plot panel data
1740    J1=J2                         ! J1=index of first value of a panel
1750    IF Pan>1 THEN 1780
1760    J2=J1+Nvp1-1
1770    GOTO 1820
1780    IF Pan=Npan THEN 1810
1790    J2=J1+Nvp2-1                  ! J2=index of last value--interior panel
1800    GOTO 1820
1810    J2=NO                         ! J2=index of last value in last panel
1820    J3=J2-J1+1                    ! J3=number of values within a panel
1830    LDIR 0                        ! Letter direction for PN's
1840    LORG 2                        ! Letter origin for PN's
1850    GOSUB Print_pn                ! Print PN's along lower edge of panel
1860    LORG 8
1870    GOSUB Print_seq               ! Print seq. num. along top edge of panel
1880    IF Pan>1 THEN 1910
1890    LOCATE B1+10,B2-10,B4,B9      ! Set up elev frame for panel 1
1900    GOTO 1950
1910    IF Pan=Npan THEN 1940
1920    LOCATE B1+10,B2-10,B4,B5      ! Set up elev frame for interior panels
1930    GOTO 1950
1940    LOCATE B1+10,B2-10,B5-(NO-J1)*Gs,B5  ! Set up elev frame for last panel
1950    FRAME
1960    MOVE B1+10,100
1970    IF Pan>1 THEN 2030
1980    LOCATE B1+10,B2-10,B4,B9      ! Plot area for elev for panel 1
1990    SCALE Bot_elev,Top_elev,0,B9  ! Scale for elev for panel 1
2000    GRID Ei,B9                    ! Plot grid for elevations, panel 1
```

```
2010    Y2=B9
2020    GOTO 2130
2030    IF Pan=Npan THEN 2090
2040    LOCATE B1+10,B2-10,B4,B5      ! Plot area for elev--interior panels
2050    SCALE Bot_elev,Top_elev,0,B5 ! Scale for elev for interior panels
2060    GRID Ei,B5                   ! Plot grid for elevations
2070    Y2=B5
2080    GOTO 2130
2090    LOCATE B1+10,B2-10,B5-(N0-J1)*Gs,B5       ! Plot area for last panel
2100    SCALE Bot_elev,Top_elev,B5-(N0-J1)*Gs,B5 ! Scale for elev--last panel
2110    GRID Ei,B5                   ! Plot grid for elevations
2120    Y2=B5
2130    GOSUB Plot_elev              ! Plot elevations
2140    DUMP GRAPHICS
2150    PLOTTER IS 13,"GRAPHICS"
2160    LOCATE B1,B2,B4,B5
2170    Y1=B5                        ! Starting Y position for next panels
2180  NEXT Pan
2190  PRINT LIN(2)
2200  EXIT GRAPHICS
2210  PRINTER IS 16
2220  RETURN
2230  !
2240 Print_label:                    ! Print label at top of plot
2250  LORG 6                         ! LORG 6, center and top of letters
2260  L=LEN(Info$)
2270  C$=Info$[1,L-24]
2280  MOVE B3/2,B7-1
2290  LABEL C$
2300  Pnint$=VAL$(Pnint)
2310  D$="PN int = "&Pnint$&"m"&"    Number of stations ="&Nsta$
2320  MOVE B3/2,B7-5
2330  LABEL D$
2340  LORG 1                         ! LORG 1, left and bottom of letters
2350  MOVE 0,B7-11
2360  B$=" PN             ELEVATION OF STATIONS IN METERS            SEQ"
2370  LABEL B$
2380  LORG 4                         ! LORG 4, middle and bottom of letters
2390  MOVE B3/2,B7-15
2400  LABEL E$                       ! Label vertical exaggeration
2410  Botel$=VAL$(Bot_elev)
2420  Topel$=VAL$(Top_elev)
2430  LDIR 270                       ! Rotate lettering
2440  LORG 8
2450  MOVE B1+10,B9+2
2460  LABEL Botel$
2470  MOVE B2-10,B9+2
2480  LABEL Topel$
2490  RETURN
2500  !
```

```
2510 Print_pn:                     ! Print PN along lower edge of plot
2520  Pn$=VAL$(Pn(J1))             ! First PN of the panel
2530  Y2=Y1                        ! Starting Y value
2540  MOVE 0,Y2
2550  LABEL Pn$                    ! Label first PN of the panel
2560  IF Pan>1 THEN 2600
2570  St=1
2580  IF J3<10 THEN 2600
2590  St=2
2600  FOR I=J1+St TO J2 STEP St
2610    Y2=Y2-St*Gs
2620    Pn$=VAL$(Pn(I))
2630    MOVE 0,Y2
2640    LABEL Pn$                  ! Print rest of PN's along edge
2650  NEXT I
2660  RETURN
2670  !
2680 Print_seq:                    ! Print seq no along top edge of plot
2690  Seq$=VAL$(Seq(J1))
2700  Y2=Y1
2710  MOVE B2,Y2
2720  LABEL Seq$
2730  IF Pan>1 THEN 2770
2740  St=1
2750  IF J3<10 THEN 2770
2760  St=2
2770  FOR I=J1+St TO J2 STEP St
2780    Y2=Y2-St*Gs
2790    Seq$=VAL$(Seq(I))
2800    MOVE B2,Y2
2810    LABEL Seq$
2820  NEXT I
2830  RETURN
2840  !
2850 Plot_elev:                    ! Plot elevations
2860  MOVE Elev(J1),Y2
2870  FOR I=J1+1 TO J2
2880    Y2=Y2-Gs
2890    DRAW Elev(I),Y2
2900    DRAW Bot_elev,Y2
2910    DRAW Elev(I),Y2
2920  NEXT I
2930  RETURN
2940  !
2950 Corr_list:                    ! Correct listing
2960  G$="N"
2970  INPUT "Are data corrections needed? (Y/N--default is N)",G$
2980  IF G$="N" THEN 3470
2990  G$="Y"
3000  INPUT "Is title acceptable? (Y/N--default is Y) ",G$
```

```
3010  IF G$="Y" THEN 3060
3020  PRINT "Old title:"
3030  PRINT Info$
3040  INPUT "New title:",Info$
3050  GOSUB More_corr                ! Branch for more corrections
3060  G$="Y"
3070  INPUT "Is file name acceptable? (Y/N--default is Y) ",G$
3080  IF G$="Y" THEN 3120
3090  PRINT "Old file name: ";Elev$
3100  INPUT "New file name: ",Elev$
3110  GOSUB More_corr                ! Branch for more corrections
3120  G$="N"
3130  INPUT "Do you want to change base elevation? (Y/N--default is N)",G$
3140  IF G$="N" THEN 3190
3150  INPUT "Amount of base-elevation correction (in m):",Corr
3160  FOR J=1 TO N2
3170    Elev(J)=Elev(J)+Corr
3180  NEXT J
3190  G$="Y"
3200  INPUT "Do you want to corr values? (Y/N--default is Y)",G$
3210  IF G$="N" THEN 3470
3220  PRINT "LIST OF QUANTITES FOR CORRECTION"
3230  PRINT "   1. Sequence number"
3240  PRINT "   2. PN"
3250  PRINT "   3. Elevation"
3260  INPUT "Correction quantity--enter number from above list =",N4
3270  INPUT "Sequence number of unacceptable entry = ",N
3280  ON N4 GOTO 3290,3330,3370
3290  PRINT "Old Seq number = ";Seq(N)
3300  INPUT "New Seq number = ",Seq(N)
3310  PRINT "New Seq number = ";Seq(N)
3320  GOTO 3400
3330  PRINT "Old PN = ";Pn(N)
3340  INPUT "New PN = ",Pn(N)
3350  PRINT "New PN = ";Pn(N)
3360  GOTO 3400
3370  PRINT "Old elevation at PN ";Pn(N);" = ";Elev(N)
3380  INPUT "New elevation = ",Elev(N)
3390  PRINT "New elevation at PN ";Pn(N);" = ";Elev(N)
3400  G$="N"
3410  INPUT "Do you want to correct another entry? (Y/N--default is N)",G$
3420  IF G$="Y" THEN 3220
3430  G$="Y"
3440  INPUT "Do you want to tabulate again? (Y/N--default is Y)",G$
3450  IF G$="N" THEN 3470
3460  GOSUB Tab_list                 ! Tabulate with corr values included
3470  RETURN
3480  !
3490 More_corr:                      ! Querry on addition corrections
3500  G$="N"
```

```
3510  INPUT "Are more corrections required? (Y/N--default is N)",G$
3520  IF G$="N" THEN 3430
3530  RETURN
3540  !
3550 Store_elev:                    ! Store elevation list (disk/tape)
3560  G$="Y"
3570  INPUT "Do you want to store list? (Y/N--default is Y) ",G$
3580  IF G$="N" THEN 3930
3590  Q1=1                          ! Q1=1; flag for first-time storage
3600  G$="Y"
3610  INPUT "Is this a first-time storage? (Y/N--default is Y)",G$
3620  IF G$="Y" THEN 3640           ! Branch; first-time storage
3630  Q1=2                          ! Q1=2; flag to signal PURGE required
3640  G$="Y"
3650  INPUT "Do you want to store list on tape? (Y/N--default is Y) ",G$
3660  IF G$="N" THEN 3770
3670  Q3=1                          ! Q3=1; flag to store data on tape
3680  MASS STORAGE IS ":T15"
3690  BEEP
3700  PRINT LIN(1);"INSERT TAPE CONTAINING ELEVATION LIST IN T15"
3710  GOSUB Ready                   ! Ready to proceed?
3720  DISP " Storing list on tape"
3730  GOTO 3800
3740  G$="Y"
3750  INPUT "Do you also want to store list on disk? (Y/N--default is Y) ",G$
3760  IF G$="N" THEN 3930
3770  Q3=2                          ! Q3=2; flag to store data on disk
3780  MASS STORAGE IS ":S7"
3790  DISP " Storing list on disk"
3800  K=14*N0+90
3810  Nrec=INT(K/256)+INT(K/65536)+3
3820  IF Q1=1 THEN 3840             ! Branch; new file--original listing
3830  PURGE Elev$
3840  CREATE Elev$,Nrec
3850  ASSIGN #1 TO Elev$
3860  PRINT #1;Info$,Pnint
3870  FOR J=1 TO N0
3880    PRINT #1;Seq(J),Pn(J),Elev(J)
3890  NEXT J
3900  IF Q3=2 THEN 3920
3910  GOTO 3740
3920  MASS STORAGE IS ":T15"
3930  RETURN
3940  !
3950 Ready:                         ! Ready to proceed?
3960  G$="Y"
3970  INPUT "Are you ready to proceed? (Y/N--default is Y) ",G$
3980  IF G$="N" THEN 3960
3990  RETURN
4000  !
```

```
4010 Read_elev:                    ! Read stored elevation data
4020  G$="Y"
4030  INPUT "Do you want to read elev data from tape? (Y/N--default is Y)",G$
4040  IF G$="Y" THEN 4090
4050  Q1=2                         ! Q1=2; flag to read data from disk
4060  MASS STORAGE IS ":S7"
4070  DISP "READING ELEVATION DATA FROM DISK"
4080  GOTO 4140
4090  BEEP
4100  PRINT LIN(1);"INSERT ELEVATION DATA TAPE IN T15"
4110  GOSUB Ready                  ! Ready to proceed
4120  MASS STORAGE IS ":T15"
4130  DISP "READING ELEVATION DATA FROM TAPE"
4140  ASSIGN #1 TO Elev$
4150  READ #1;Info$,Pnint
4160  L=LEN(Info$)
4170  Nelev$=Info$[L-3,L]
4180  NO=VAL(Nelev$)               ! Number of elevations along line
4190  FOR J=1 TO NO
4200    READ #1;Seq(J),Pn(J),Elev(J)
4210  NEXT J
4220  PRINT Info$
4230  PRINT "PN at beginning of line:";Pn(1)
4240  Pn1=Pn(1)
4250  PRINT "PN at end of line:";Pn(NO)
4260  Pn2=Pn(NO)
4270  REDIM Elev(NO),Pn(NO),Seq(NO)
4280  MASS STORAGE IS ":T15"
4290  RETURN
4300  !
4310 Tab_list:                     ! Tabulate elevation list
4320  G$="Y"
4330  INPUT "Do you want to tabulate list? (Y/N--default is Y)",G$
4340  IF G$="N" THEN 4490
4350  IMAGE 4(3D,X,4D,2X,4D.D,3X)
4360  G$="Y"
4370  INPUT "Do you want printout of list? (Y/N--default is Y)",G$
4380  IF G$="N" THEN 4400
4390  PRINTER IS 0
4400  PRINT LIN(1);Info$
4410  PRINT "PN interval in m =";Pnint;"  Data file name: ";Elev$
4420  PRINT "SEQ   PN   ELEV    SEQ   PN   ELEV    SEQ   PN   ELEV    SEQ   PN   ELEV"
4430  ON ERROR GOTO 4470
4440  FOR J=1 TO NO STEP 4
4450    PRINT USING 4350;Seq(J),Pn(J),Elev(J),Seq(J+1),Pn(J+1),Elev(J+1),Seq(J+2),Pn(J+2),Elev(J+2),Seq(J+3),Pn(J+3),Ele
v(J+3)
4460  NEXT J
4470  PRINT LIN(2)
4480  PRINTER IS 16
4490  RETURN
```

```
10    PRINT "PROGRAM 'HRFB'   LAST REVISION: 5 NOV 1988"
20    PRINT "PROGRAM TO ENTER, APPEND, CORRECT, AND STORE FIRST BREAKS "
30    PRINT "TAKEN WITH HIGH REDUNDANCY REFRACTION PROCEDURE"
40    OPTION BASE 1
50    PRINTER IS 16
60    PRINT LIN(1);"NOTE: Spreads and their offsets must be consistent"
70    DIM A$[18],G$[1],Info$[80],Li$[19]
80    INTEGER Spf(100),Spr(100)
90    SHORT Tf(100,24),Tr(100,24)
100   GOSUB Title                ! Enter list title and file name data
110   GOSUB Sp_spread            ! Enter SP and spread information
120   GOSUB Enter                ! Enter first breaks
130   GOSUB Tab_list             ! Tabulate first breaks
140   GOSUB Corr_list            ! Correct values within list
150   GOSUB Store_list           ! Store first breaks (disk/tape)
160   BEEP
170   DISP "PROGRAM COMPLETED"
180   END
190   !
200 Title:                       ! Enter list title and file name data
210   PRINT "ENTER FIRST FOUR SYMBOLS FOR 6-CHAR FILE NAME AS PROMPTED"
220   INPUT "One-letter area designation: ",B$
230   Y$="8"
240   INPUT "Single number for year (example: 1988=8, default=8): ",Y$
250   INPUT "Line number (max = 99, if <10, prefix with 0): ",L$
260   Name$=B$&Y$&L$&"FB"
270   PRINT "File name = ";Name$
280   G$="Y"
290   INPUT "Is file name OK? (Y/N--default is Y)",G$
300   IF G$="Y" THEN 320
310   GOTO 210                   ! Re-enter file name
320   Q2=1              ! Q2=1; flag for no data to be appended or corrected
330   G$="N"
340   INPUT "Do you want to correct tabulate or append a previous list? (Y/N--default is N)",G$
350   IF G$="N" THEN 380
360   GOSUB Append               ! Append tabulate or correct a previous list
370   GOTO 150
380   PRINT LIN(1);"ENTER LIST TITLE INFORMATION AS PROMPTED"
390   INPUT "Area (15 char,max): ",A$
400   PRINT "        Area name = ";A$
410   A$=A$&"   "
420   INPUT "Line number (5 char,max): ",Li$
430   PRINT "      Line number = ";Li$
440   Li$="  Line "&Li$&"  "
450   INPUT "Direction of line, north azimuth",Dir
460   Dir$=VAL$(Dir)
470   PRINT "   Line direction = ";Dir$
```

```
480   Pnint=1.5
490   INPUT "PN interval, (express in m/PN--default is 1.5 m/PN)",Pnint
500   PRINT "      PN interval =";Pnint
510   INPUT "Number of record pairs",N1
520   N2=2*N1                       ! Total number of records along line
530   N2$=VAL$(N2)
540   PRINT "Number of records = ";N2$
550   Info$=A$&Li$&" Dir="&Dir$&" N az"&"   No. of records ="&"   "&N2$
560   PRINT LIN(1);"TITLE AND NAME OF FIRST BREAK FILE"
570   PRINT Info$
580   PRINT Name$
590   G$="Y"
600   INPUT "Are the title and file name OK? (Y/N--default is Y)",G$
610   IF G$="Y" THEN 630
620   GOTO 210
630   RETURN
640   !
650 Sp_spread:                      ! Enter SP and spread information
660   PRINT LIN(1);"ENTER SP AND SPREAD INFORMATION AS PROMPTED"
670   Nd=12
680   INPUT "Number of groups (traces) for each spread (default=12):",Nd
690   REDIM Tf(100,Nd),Tr(100,Nd)
700   PRINT "   Number of groups per spread =";Nd
710   Grd=3
720   INPUT "Distance between adjacent groups (default=3m)",Grd
730   PRINT "      Group interval in meters =";Grd
740   Gr_int=Grd/Pnint              ! Group interval in PN's
750   PRINT "         Group interval in PN's =";Gr_int
760   Jump_dist=12
770   INPUT "  Spread advance interval (default=12m):",Jump_dist
780   PRINT "  Spread advance interval in m =";Jump_dist
790   Jump=Jump_dist/Pnint          ! Jump=number of PN's jumped
800   PRINT "    PN spread advance interval =";Jump
810   PRINT "A forward spread is one for which PN at seis > PN at SP"
820   Spf(1)=1
830   INPUT "PN at first SP for first forward spread (default=1):",Spf(1)
840   PRINT "SP PN for first forward spread =";Spf(1)
850   Os_near=3
860   INPUT "Offset distance to near detector (default=3m):",Os_near
870   PRINT "  Offset dist to near detector =";Os_near
880   Osn=Os_near/Pnint             ! Offset to near detector in PN's
890   PRINT "A reverse spread is one for which PN at seis < PN at SP"
900   Dfl=(Nd-1)*Gr_int+Osn         ! PN difference from 1st to last trace
910   Spr(1)=Spf(1)+Dfl             ! PN of first reverse SP
920   PRINT "SP PN for first reverse spread = ";Spr(1)
930   N4=1                          ! N4=Number of first record in sequences
940   N5=N1                         ! N5=Number of last record in sequences
950   G$="Y"
```

```
960  INPUT "Are SP and spread information OK? (Y/N--default is Y)",G$
970  IF G$="Y" THEN 990
980  GOTO 660                    ! Re-enter information
990  RETURN
1000 !
1010 Enter:                      ! Enter first break times from keyboard
1020 PRINT LIN(1);"ENTER FIRST BREAK TIMES FOR ALL FORWARD SPREADS ALONG LINE"
1030 IF Q2=1 THEN 1060           ! Branch; no corrected or appended values
1040 Spn=Spf(N4-1)
1050 GOTO 1070
1060 Spn=Spf(N4)-Jump
1070 FOR J=N4 TO N5
1080   Spn=Spn+Jump
1090   Spf(J)=Spn
1100   Spr(J)=Spn+Dfl
1110   PRINT "For record from SP";Spf(J);"into spread from PN";Spf(J)+Osn;"to";Spr(J)
1120   FOR K=1 TO Nd
1130     PRINT "First break time for trace ";K;" = ";
1140     INPUT "FB time = ",Tf(J,K)
1150     PRINT Tf(J,K)
1160   NEXT K
1170   G$="Y"
1180   INPUT "Are above values acceptable? (Y/N--default is Y)",G$
1190   IF G$="Y" THEN 1240
1200   INPUT "Trace with incorrect time",I
1210   INPUT "Correct fb time = ",Tf(J,I)
1220   PRINT "Corrected time for trace";I;"=";Tf(J,I)
1230   GOTO 1170
1240 NEXT J
1250 PRINT LIN(1);"ENTER FIRST BREAK TIMES FOR ALL REVERSE SPREADS ALONG LINE"
1260 IF Q2=1 THEN 1300           ! Branch; no corrected or appended values
1270 Spn=Spr(N4-1)
1280 GOTO 1300
1290 Spn=Spr(N4)-Jump
1300 FOR J=N4 TO N5
1310   Spn=Spn+Jump
1320   PRINT "For record from SP";Spr(J);"into spread from PN";Spf(J);"to";Spr(J)-Osn
1330   FOR K=1 TO Nd
1340     PRINT "First break time for trace ";K;" = ";
1350     INPUT "FB time = ",Tr(J,K)
1360     PRINT Tr(J,K)
1370   NEXT K
1380   G$="Y"
1390   INPUT "Are above values acceptable? (Y/N--default is Y)",G$
1400   IF G$="Y" THEN 1450
1410   INPUT "Trace with incorrect time",I
1420   INPUT "Correct fb time = ",Tr(J,I)
1430   PRINT "Corrected time for trace";I;"=";Tr(J,I)
```

```
1440     GOTO 1380
1450   NEXT J
1460   RETURN
1470   !
1480 Tab_list:                   ! Tabulate first break times
1490   G$="Y"
1500   INPUT "Do you want to tabulate first breaks? (Y/N--default is Y) ",G$
1510   IF G$="N" THEN 1790
1520   PRINTER IS 0
1530   G$="Y"
1540   INPUT "Do you want to tabulate all records? (Y/N--default is Y)",G$
1550   IF G$="Y" THEN 1590
1560   INPUT "First record number:",L1
1570   INPUT "Last record number:",L2
1580   GOTO 1610
1590   L1=1
1600   L2=N1
1610   PRINT LIN(1);Info$
1620   PRINT "Tape/disk data-file name: ";Name$
1630   PRINT LIN(1);"TRACE NUMBERS AND FIRST BREAK TIMES FOR FORWARD SPREADS"
1640   IMAGE 6(2D,X,3D.D,4X)
1650   FOR J=L1 TO L2
1660     PRINT LIN(1);"For record";J;"   SP";Spf(J);"into spread from PN";Spf(J)+Osn;"to";Spr(J)
1670     FOR K=1 TO Nd STEP 6
1680       PRINT USING 1640;K,Tf(J,K),K+1,Tf(J,K+1),K+2,Tf(J,K+2),K+3,Tf(J,K+3),K+4,Tf(J,K+4),K+5,Tf(J,K+5)
1690     NEXT K
1700   NEXT J
1710   PRINT LIN(2);"TRACE NUMBERS AND FIRST BREAK TIMES FOR REVERSE SPREADS"
1720   FOR J=L1 TO L2
1730     PRINT LIN(1);"For record";J;"   SP";Spr(J);"into spread from PN";Spf(J);"to";Spr(J)-Osn
1740     FOR K=1 TO Nd STEP 6
1750       PRINT USING 1640;K,Tr(J,K),K+1,Tr(J,K+1),K+2,Tr(J,K+2),K+3,Tr(J,K+3),K+4,Tr(J,K+4),K+5,Tr(J,K+5)
1760     NEXT K
1770   NEXT J
1780   PRINTER IS 16
1790   RETURN
1800   !
1810 Corr_list:                  ! Correct listing
1820   G$="N"
1830   INPUT "Do you want to correct list? (Y/N--default is N)",G$
1840   IF G$="N" THEN 2230
1850   G$="Y"
1860   INPUT "Is title correct? (Y/N--default is Y) ",G$
1870   IF G$="Y" THEN 1900
1880   PRINT "Current title: ";Info$
1890   INPUT "New title:",Info$
1900   G$="Y"
1910   INPUT "Is file name correct? (Y/N--default is Y) ",G$
```

```
1920  IF G$="Y" THEN 1990
1930  PRINT "Current file name: ";Name$
1940  G$="N"
1950  INPUT "Do you want to purge current file name? (Y/N--default is N)",G$
1960  IF G$="N" THEN 1980
1970  PURGE Name$
1980  INPUT "New file name: ",Name$
1990  G$="Y"
2000  INPUT "Are first break times correct? (Y/N--default is Y)",G$
2010  IF G$="Y" THEN 2230
2020  G$="Y"
2030  INPUT "Do you want to correct a forward-spread value?(Y/N--default is Y)",G$
2040  IF G$="Y" THEN 2110
2050  INPUT "Record number (first index) = ",I1
2060  INPUT "Trace number (second index) = ",I2
2070  PRINT "Current value =";Tr(I1,I2)
2080  INPUT "Correct value should = ",Tr(I1,I2)
2090  PRINT "Corrected value =";Tr(I1,I2)
2100  GOTO 2160
2110  INPUT "Record number (first index) = ",I1
2120  INPUT "Trace number (second index) = ",I2
2130  PRINT "Current value =";Tf(I1,I2)
2140  INPUT "Correct value should = ",Tf(I1,I2)
2150  PRINT "Corrected value =";Tf(I1,I2)
2160  G$="N"
2170  INPUT "Do you want to correct another entry? (Y/N--default is N)",G$
2180  IF G$="Y" THEN 2020
2190  G$="Y"
2200  INPUT "Do you want to tabulate again? (Y/N--default is Y)",G$
2210  IF G$="N" THEN 2230
2220  GOSUB Tab_list              ! Tabulate with corrected values included
2230  RETURN
2240  !
2250 Store_list:                  ! Store first break data (disk/tape)
2260  G$="Y"
2270  INPUT "Do you want to store list? (Y/N--default is Y) ",G$
2280  IF G$="N" THEN 2600
2290  G$="Y"
2300  INPUT "Do you want to store list on tape? (Y/N--default is Y) ",G$
2310  IF G$="N" THEN 2390
2320  Q3=1                        ! Q3=1; flag to store data on tape
2330  MASS STORAGE IS ":T15"
2340  BEEP
2350  PRINT LIN(1);"INSERT TAPE CONTAINING FIRST BREAK LIST IN T15"
2360  GOSUB Ready                 ! Ready to proceed?
2370  DISP " STORING LIST ON TAPE"
2380  GOTO 2450
2390  G$="Y"
```

```
2400  INPUT "Do you want to store list on disk? (Y/N--default is Y) ",G$
2410  IF G$="N" THEN 2600
2420  Q3=2                          ! Q3=2; flag to store data on disk
2430  MASS STORAGE IS ":S7"
2440  DISP " STORING LIST ON DISK"
2450  K=72*N2+90
2460  Nrec=INT(K/256)+INT(K/65536)+3
2470  IF Q2=1 THEN 2490             ! Branch; new file
2480  PURGE Name$
2490  CREATE Name$,Nrec
2500  ASSIGN #1 TO Name$
2510  PRINT #1;Info$,Pnint,Osn
2520  FOR J=1 TO N1
2530    PRINT #1;Spf(J),Spr(J)
2540    FOR K=1 TO Nd
2550      PRINT #1;Tf(J,K),Tr(J,K)
2560    NEXT K
2570  NEXT J
2580  IF Q3=1 THEN 2390
2590  MASS STORAGE IS ":T15"
2600  RETURN
2610  !
2620 Ready:                         ! Ready to proceed?
2630  G$="Y"
2640  INPUT "Are you ready to proceed? (Y/N--default is Y) ",G$
2650  IF G$="N" THEN 2630
2660  RETURN
2670  !
2680 Append:                        ! Append tabulate or correct a previous list
2690  Q1=1                          ! Q1=1; flag to read data from tape
2700  Q2=2                          ! Q2=2; flag to append or correct data
2710  Nd=12
2720  INPUT "Number of groups (traces) for each spread (default=12):",Nd
2730  PRINT "  Number of groups per spread =";Nd
2740  G$="Y"
2750  INPUT "Do you want to read data from tape? (Y/N--default is Y)",G$
2760  IF G$="Y" THEN 2810
2770  Q1=2                          ! Q1=2; flag to read data from disk
2780  MASS STORAGE IS ":S7"
2790  DISP "READING DATA STORED ON DISK"
2800  GOTO 2860
2810  MASS STORAGE IS ":T15"
2820  BEEP
2830  PRINT LIN(1);"INSERT TAPE CONTAINING FB DATA IN T15"
2840  GOSUB Ready                   ! Ready to proceed
2850  DISP "READING DATA STORED ON TAPE"
2860  ASSIGN #2 TO Name$
2870  READ #2;Info$,Pnint,Osn
```

```
2880  L=LEN(Info$)
2890  N$=Info$[L-3,L]
2900  N2=VAL(N$)                ! Previous total number of records taken
2910  N1=N2/2                   ! Previous total number of SP pairs
2920  IF N1>=2 THEN 2980
2930  BEEP
2940  PRINT "ERROR: At least two data sets musts have been stored"
2950  PRINT "Therefore will have to start from beginning of line"
2960  Q2=1                      ! Flag for append removed
2970  GOTO 100                  ! Start over from first record
2980  FOR J=1 TO N1             ! Read stored data
2990    READ #2;Spf(J),Spr(J)
3000    FOR K=1 TO Nd
3010      READ #2;Tf(J,K),Tr(J,K)
3020    NEXT K
3030  NEXT J
3040  GOSUB Tab_list            ! Tabulate data
3050  GOSUB Corr_list           ! Correct listing
3060  G$="N"
3070  INPUT "Do you want to append list? (Y/N--default is N)",G$
3080  IF G$="N" THEN 3280
3090  BEEP
3100  PRINT LIN(1);"NOTE: APPENDED DATA MUST BE WITH SAME SPREAD OFFSETS"
3110  Jump=Spf(2)-Spf(1)        ! Amount of spread advance in PN's
3120  Dfl=Spr(1)-Spf(1)        ! Difference in PN's from 1st to last seis
3130  INPUT "Number of additional SP pairs:",N3
3140  PRINT "Number of additional SP pairs =";N3
3150  N1=N1+N3                  ! New total number of SP pairs
3160  N2=2*N1                   ! New total number of records
3170  N2$=VAL$(N2)
3180  Ln2=LEN(N2$)
3190  ON Ln2 GOTO 3200,3220,3230
3200  N2$="  "&N2$
3210  GOTO 3230
3220  N2$=" "&N2$
3230  Info$=Info$[1,L-3]&"= "&N2$
3240  PRINT Info$
3250  N4=N1+1-N3
3260  N5=N1
3270  GOSUB Enter               ! Enter additional first break times
3280  RETURN
3290  !
```

```
10    PRINT "PROGRAM 'HRCRT'   LAST REVISION : 23 MARCH 1990"
20    PRINT "PROGRAM TO PLOT HIGH-REDUNDANCY FIRST ARRIVALS ON CRT"
30    PRINT "Maximum number of detectors per spread = 24"
40    OPTION BASE 1
50    OVERLAP
60    !
70    DIM B$[80],C$[80],D$[80],Info$[80],Infor$[80]
80    DIM Maxtf(210),Maxtr(210),Mintf(210),Mintr(210)
90    DIM T1(210,24),T2(210,24)
100   SHORT Ele(240),Elev(240),Tp1(210,24),Tp2(210,24)
110   INTEGER Pn(240),Posn(240),Seq(240),Sppn1(210),Sppn2(210)
120   !
130   GOSUB File_name                ! Enter file name
140   GOSUB Read_fb                  ! Read first-break times
150   GOSUB Read_elev                ! Read elevation data
160   GOSUB Tab_in_data              ! Tabulate input data
170   GOSUB Plot_fb_elev             ! Plot first breaks and elevations
180   BEEP
190   DISP "PROGRAM COMPLETED"
200   END
210   !
220 Ready:                           ! Ready to proceed
230   BEEP
240   G$="Y"
250   INPUT "ARE YOU READY TO PROCEED? (Y/N--default is Y)",G$
260   IF G$="N" THEN 240
270   RETURN
280   !
290 File_name:                       ! Enter file name
300   PRINTER IS 16
310   Q1=1                           ! Q1=1; flag to read/store tape data
320   INPUT "Data date (14 char,max):",Data_date$
330   PRINT LIN(1);"ENTER SYMBOLS FOR 6-CHAR FILE NAME"
340   INPUT "One-letter area designation; ",B$
350   Y$="8"                                                        ! DEFAULT
360   INPUT "Single number for year (example: 1988=8--default=8)",Y$
370   INPUT "Line number (max=99, if <10, prefix with 0);",L$
380   Na$=B$&Y$&L$
390   Fb$=Na$&"FB"
400   Elev$=Na$&"EL"
410   PRINT LIN(1);" File name for first break times: ";Fb$
420   PRINT "        File name for elevations: ";Elev$
430   G$="N"
440   INPUT "Do you want to change file names? (Y/N--default is N)",G$
450   IF G$="N" THEN 470
460   GOTO 340
470   Nd=12                                                         ! DEFAULT
480   INPUT "Number of detectors per record (default=12):",Nd
490   PRINT "   Number of detectors per record =";Nd
```

```
500   RETURN
510   !
520 Read_fb:                        ! Read stored first-break data
530   G$="Y"
540   INPUT "Do you want to read fb data from tape? (Y/N--default is Y)",G$
550   IF G$="Y" THEN 600
560   Q1=2                          ! Q1=2; flag to read data from disk
570   MASS STORAGE IS ":S7"
580   DISP "READING FIRST BREAK DATA FROM DISK"
590   GOTO 650
600   BEEP
610   PRINT LIN(1);"INSERT FIRST BREAK DATA TAPE IN T15"
620   GOSUB Ready                   ! Ready to proceed
630   MASS STORAGE IS ":T15"
640   DISP "READING FIRST BREAK DATA STORED ON TAPE"
650   ASSIGN #2 TO Fb$
660   READ #2;Info$,Pnint,Osn
670   L=LEN(Info$)
680   N2$=Info$[L-2,L]
690   N2=VAL(N2$)                   ! Total number of records along line
700   N1=N2/2                       ! Total number of SP pairs along line
710   REDIM Sppn1(N1),Sppn2(N1)     ! Redimension for J= N1 and K=Nd
720   REDIM Maxtf(N1),Mintf(N1),Maxtr(N1),Mintr(N1)
730   REDIM T1(N1,Nd),T2(N1,Nd),Tp1(N1,Nd),Tp2(N1,Nd)
740   FOR J=1 TO N1
750     READ #2;Sppn1(J),Sppn2(J)
760     FOR K=1 TO Nd
770       READ #2;T1(J,K),T2(J,K)
780     NEXT K
790   NEXT J
800   Jump=Sppn1(2)-Sppn1(1)        ! Jump=spread advance in terms of PN's
810   Jp=Jump/2
820   PRINT "Title information from first-break data file"
830   PRINT Info$
840   PRINT "ENTER PLOT TITLE USING ABOVE INFORMATION"
850   INPUT "Title:",C$
860   PRINT "Full title"
870   C$=C$&" "&Data_date$
880   PRINT C$
890   G$="N"
900   INPUT "Do you want to change title? (Y/N--default is N)",G$
910   IF G$="N" THEN 930
920   GOTO 850
930   PRINT "    Position Number (PN) interval =";Pnint;"m/PN"
940   PRINT "           PN of first forward SP =";Sppn1(1)
950   PRINT "            PN of last reverse SP =";Sppn2(N1)
960   PRINT "  Total number of SP's along line =";N2
970   PRINT "  Spread advance in terms of PN's =";Jump
980   NO=(Sppn2(N1)-Sppn1(1))/2+1    ! Total number of seis along line
990   REDIM Elev(NO),Pn(NO)
```

```
1000 PRINT "Total number of detectors on line =";N0
1010 PRINT "          Offset to near detector =";Osn*Pnint;"m"
1020 RETURN
1030 !
1040 Read_elev:                    ! Read stored elevation data
1050 G$="Y"
1060 INPUT "Do you want to read elev data from tape? (Y/N--default is Y)",G$
1070 IF G$="Y" THEN 1120
1080 Q1=2                          ! Q1=2; flag to read data from disk
1090 MASS STORAGE IS ":S7"
1100 DISP "READING ELEVATION DATA FROM DISK"
1110 GOTO 1170
1120 BEEP
1130 PRINT LIN(1);"INSERT ELEVATION DATA TAPE IN T15"
1140 GOSUB Ready                   ! Ready to proceed
1150 MASS STORAGE IS ":T15"
1160 DISP "READING ELEVATION DATA FROM TAPE"
1170 ASSIGN #1 TO Elev$
1180 READ #1;Infor$,Pnint
1190 L=LEN(Infor$)
1200 Nelev$=Infor$[L-3,L]
1210 Nelev=VAL(Nelev$)             ! Number of elevations along line
1220 FOR J=1 TO Nelev
1230   READ #1;Seq(J),Posn(J),Ele(J)
1240 NEXT J
1250 I_elev=(Sppn1(1)-Posn(1))/2   ! Elev index at first forward SP
1260 FOR J=1 TO N0                 ! Re-order elevations and PN's
1270   Elev(J)=Ele(J+I_elev)
1280   Pn(J)=Posn(J+I_elev)
1290 NEXT J
1300 RETURN
1310 !
1320 Tab_in_data:                  ! Tabulate input data
1330 G$="N"
1340 INPUT "Do you want to tabulate input data? (Y/N--default is N)",G$
1350 IF G$="N" THEN 1740
1360 PRINTER IS 0
1370 PRINT LIN(1);Info$
1380 PRINT "First breaks file name: ";Fb$;"     Elevations file name: ";Elev$
1390 IMAGE #,6(4D.D,X,3D.D,X)/
1400 PRINT LIN(1);"ELEV AND FB TIMES FOR TRACES 1 THRU";Nd;"FOR FORWARD SPREADS"
1410 I1=1-Jp
1420 FOR J=1 TO N1
1430   Seis1=Sppn1(J)+Osn
1440   Seis12=Sppn2(J)
1450   I1=I1+Jp
1460   I=I1+Osn/2
1470   PRINT "For record from SP";Sppn1(J);" at elev=";Elev(I1);"into spread from PN";Seis1;"to";Seis12
1480   FOR K=1 TO Nd STEP 6
1490     PRINT USING 1390;Elev(I),T1(J,K),Elev(I+1),T1(J,K+1),Elev(I+2),T1(J,K+2),Elev(I+3),T1(J,K+3),Elev(I+4),T1(
```

```
4),Elev(I+5),T1(J,K+5)
1500      I=I+6
1510    NEXT K
1520  NEXT J
1530  PRINT LIN(1);"ELEV AND FB TIMES FOR TRACES 1 THRU";Nd;"FOR REVERSE SPREADS"
1540  I1=(Sppn2(1)-Jump)/2
1550  I2=(Sppn1(1)-Jump)/2
1560  FOR J=1 TO N1
1570    Seis1=Sppn1(J)
1580    Seis12=Seis1+2*(Nd-1)
1590    I1=I1+Jp
1600    I2=I2+Jp
1610    I=I2
1620    PRINT "For record from SP";Sppn2(J);" at elev=";Elev(I1);"into spread from PN";Seis1;"to";Seis12
1630    FOR K=1 TO Nd STEP 6
1640      PRINT USING 1390;Elev(I),T2(J,K),Elev(I+1),T2(J,K+1),Elev(I+2),T2(J,K+2),Elev(I+3),T2(J,K+3),Elev(I+4),T2(
4),Elev(I+5),T2(J,K+5)
1650      I=I+6
1660    NEXT K
1670  NEXT J
1680  G$="Y"
1690  INPUT "Are the tabulated data acceptable? (Y/N--default is Y)",G$
1700  IF G$="Y" THEN 1720
1710  PRINT "IF NOT OK, THEN RETURN TO SPECIFIC DATA ENTRY PROGRAM"
1720  PRINT LIN(3)
1730  PRINTER IS 16
1740  RETURN
1750  !
1760 Plot_fb_elev:                  ! Plot first breaks and elevations
1770  Q7=3                          ! Q7=3; flag for forward and reverse
1780  Plot=1                        ! Plot=1; flag for bottom border = 0
1790  MAT Tp1=T1                    ! Plot values = raw TB's, forward spd
1800  MAT Tp2=T2                    ! Plot values = raw TB's, reverse spd
1810  G$="Y"
1820  PRINTER IS 16
1830  INPUT "Do you want forward and reverse on same plot? (Y/N--default is Y)",G$
1840  IF G$="Y" THEN 1910
1850  G$="Y"
1860  INPUT "Do you want only the forward results? (Y/N--default is Y)",G$
1870  IF G$="N" THEN 1900
1880  Q7=1                          ! Q7=1; flag for forward-spread plot only
1890  GOTO 1910
1900  Q7=2                          ! Q7=2; flag for reverse-spread plot only
1910  G$="Y"
1920  INPUT "Do you want to plot all tabulated data? (Y/N--default is Y)",G$
1930  IF G$="Y" THEN 2030
1940  INPUT "Forward SP at which plot is to begin:",Spstart
1950  INPUT "Forward SP at which plot is to end:",Spend
1960  J4=(Spstart-Sppn1(1))/8+1     ! J index of T1(J,K) start times
1970  J5=(Spend-Sppn1(1))/8+1       ! J index of T1(J,K) end times
```

```
1980 Nrec=J5-J4+1                    ! Number of forward records
1990 I1=4*(J4-1)+1                   ! I index for starting elev & PN
2000 I2=4*(J5-1)+1+Nd                ! I index for ending elev & PN
2010 Nsta=I2-I1+1                    ! Number of station to be plotted
2020 GOTO 2090
2030 J4=1                            ! J index of first forward refr. time
2040 J5=N1                           ! J index of last forward refr. time
2050 Nrec=N1
2060 I1=1                            ! I index of first forward refr. time
2070 I2=N0                           ! I index of last forward refr. time
2080 Nsta=N0                         ! Number of stations to be plotted
2090 PRINT "Number of detector positions to be plotted =";Nsta
2100 INPUT "Number of values wanted in first panel (must be odd number):",Nvp1
2110 PRINT "          Number of values in first panel =";Nvp1
2120 Nvp2=2*Nvp1-1
2130 Ns=Nvp1-1                       ! Number of spaces in panel no. 1
2140 Ns2=2*Ns                        ! Number of spaces in panels > no. 1
2150 FOR P=1 TO 100
2160   Ns=Ns+Ns2
2170   IF Ns>=Nsta-1 THEN 2190
2180 NEXT P
2190 Npan=P+1
2200 PRINT "                Number of panels required =";Npan
2210 Nlast=Nsta-(Ns-2*(Nvp1-1))
2220 PRINT "           Number of values in last panel =";Nlast
2230 IF Npan>=2 THEN 2270
2240 BEEP
2250 PRINT "ERROR: NUMBER OF PANELS MUST BE >=2. RESELECT NO. OF POINTS IN PANEL 1"
2260 GOTO 2100
2270 G$="N"
2280 INPUT "Do you want to change number of points in panel 1? (Y/N--default is N)",G$
2290 IF G$="N" THEN 2310
2300 GOTO 2100
2310 Ngdu=100*Npan-50                ! Total number of GDU's for all panels
2320 Gs=Ngdu/Ns                      ! Number of GDU's per plot station space
2330 MAT SEARCH Elev(*),MAX;Max_elev
2340 MAT SEARCH Elev(*),MIN;Min_elev
2350 PRINT LIN(1)
2360 IMAGE "Min elev = ",4D.D,"  Max elev = ",4D.D
2370 PRINT USING 2360;Min_elev,Max_elev
2380 Ei=2
2390 INPUT "Elevation increment for plot (default is 2 m):",Ei
2400 MAT Mintf=(9999)
2410 MAT Mintr=(9999)
2420 FOR J=J4 TO J5                  ! Determine max and min refraction times
2430   MAT SEARCH Tp1(J,*),MAX;Maxtf(J)
2440   MAT SEARCH Tp1(J,*),MIN;Mintf(J)
2450   MAT SEARCH Tp2(J,*),MAX;Maxtr(J)
2460   MAT SEARCH Tp2(J,*),MIN;Mintr(J)
2470 NEXT J
```

```
2480 MAT SEARCH Maxtf(*),MAX;Maxftb
2490 MAT SEARCH Mintf(*),MIN;Minftb
2500 MAT SEARCH Maxtr(*),MAX;Maxrtb
2510 MAT SEARCH Mintr(*),MIN;Minrtb
2520 Maxt=MAX(Maxftb,Maxrtb)
2530 Mint=MIN(Minftb,Minrtb)
2540 PRINT "Maximum arrival time = ";Maxt
2550 PRINT "Minimum arrival time = ";Mint
2560 Ti=10                          ! Establish plot increments
2570 INPUT "FB time increment for plot (default is 10 ms) =",Ti
2580 Top_time=INT(Maxt/Ti)*Ti+Ti    ! Establish top/bottom border values
2590 Bot_time=INT(Mint/Ti)*Ti
2600 Ra=.3*(Top_time-Bot_time)/40
2610 IF Top_time<>Bot_time THEN 2640
2620 Ti=Ti-2
2630 GOTO 2580
2640 G$="N"
2650 PRINT "Bottom border time is ";Bot_time
2660 INPUT "Do you want want bottom border time = 0? (Y/N--default is N)",G$
2670 IF G$="Y" THEN 2700
2680 Plot=2
2690 GOTO 2710
2700 Bot_time=0
2710 Top_elev=INT(Max_elev/Ei)*Ei+Ei
2720 Bot_elev=INT(Min_elev/Ei)*Ei
2730 IF Top_elev<>Bot_elev THEN 2760
2740 Ei=Ei-1
2750 GOTO 2710
2760 Elev_int=(Top_elev-Bot_elev)/Ei
2770 Elev_int=10/Elev_int
2780 PRINTER IS 0
2790 DEG
2800 PRINT LIN(2)                   ! Paper advance 2 spaces before plotting
2810 PLOTTER IS 13,"GRAPHICS"
2820 GRAPHICS
2830 RESTORE
2840 DATA 0,123.1,0,100,72,50
2850 READ B1,B2,B4,B5,B7,B9
2860 B3=B2-B1
2870 CLIP B1,B2,B4,B7
2880 GOSUB Print_label              ! Print plot label
2890 J2=I1                          ! Initialization for J1 in 'Pan' loop
2900 Y1=B9                          ! Starting Y value for panel 1
2910 FOR Pan=1 TO Npan              ! Print PN's and plot panel data
2920   J1=J2                        ! J1=index of first value of a panel
2930   IF Pan>1 THEN 2960
2940   J2=J1+Nvp1-1
2950   GOTO 3000
2960   IF Pan=Npan THEN 2990
2970   J2=J1+Nvp2-1                 ! J2=index of last value--interior panel
```

```
2980  GOTO 3000
2990  J2=NO                        ! J2=index of last value in last panel
3000  J3=J2-J1+1                   ! J3=number of values within a panel
3010  LDIR 0                       ! Letter direction for PN's
3020  LORG 2                       ! Letter origin for PN's
3030  GOSUB Print_pn               ! Print PN's along edge of panel
3040  IF Pan>1 THEN 3070
3050  CLIP B1+10,B1+20,B4,B9       ! Set up elev frame for panel 1
3060  GOTO 3110
3070  IF Pan=Npan THEN 3100
3080  CLIP B1+10,B1+20,B4,B5       ! Set up elev frame for interior panels
3090  GOTO 3110
3100  CLIP B1+10,B1+20,B5-(NO-J1)*Gs,B5  ! Set up elev frame for last panel
3110  FRAME
3120  GRID Elev_int,B5             ! Plot grid for elevations
3130  IF Pan>1 THEN 3180
3140  LOCATE B1+10,B1+20,B4,B9     ! Plot area for elev for panel 1
3150  SCALE Bot_elev,Top_elev,0,B9 ! Scale for elev for panel 1
3160  Y2=B9
3170  GOTO 3260
3180  IF Pan=Npan THEN 3230
3190  LOCATE B1+10,B1+20,B4,B5     ! Plot area for elev--interior panels
3200  SCALE Bot_elev,Top_elev,0,B5 ! Scale for elev for interior panels
3210  Y2=B5
3220  GOTO 3260
3230  LOCATE B1+10,B1+20,B5-(NO-J1)*Gs,B5      ! Plot area for last panel
3240  SCALE Bot_elev,Top_elev,B5-(NO-J1)*Gs,B5 ! Scale for elev--last panel
3250  Y2=B5
3260  GOSUB Plot_elev              ! Plot elevations
3270  IF Pan>1 THEN 3300
3280  LOCATE B1+25,B2-3,B4,B9      ! Area for FB's for panel 1
3290  GOTO 3340
3300  IF Pan=Npan THEN 3330
3310  LOCATE B1+25,B2-3,B4,B5      ! Area for FB's for interior panels
3320  GOTO 3340
3330  LOCATE B1+25,B2-3,B5-(NO-J1)*Gs,B5  ! Area for FB's for last panel
3340  FRAME                        ! Frame for FB's
3350  SCALE Bot_time,Top_time,J3-1,0   ! Scale for FB grid
3360  GRID Ti,2                    ! Plot grid for first breaks
3370  IF Pan>1 THEN 3420
3380  SCALE Bot_time,Top_time,0,B9 ! Scale for FB's--panel 1
3390  Y2=B9-(Osn/2-4)*Gs           ! Y coordinate of first seis--panel 1
3400  Y4=Y2/(2*Gs)                 ! Shift number from first panel
3410  GOTO 3470
3420  IF Pan=Npan THEN 3450
3430  SCALE Bot_time,Top_time,0,B5 ! Scale for FB's--interior panels
3440  GOTO 3460
3450  SCALE Bot_time,Top_time,B5-(NO-J1)*Gs,B5   ! Scale for FB's--last panel
3460  Y2=B5+2*Gs*(Y4+(Pan-2)*(Nvp1-1))      ! Y of 1st seis--panels>1
3470  IF Q7=2 THEN 3490            ! Plot reverse-spread FB times only
```

```
3480    GOSUB Plot_fbf               ! Plot forward spread FB times
3490    IF Pan>1 THEN 3520
3500    Y2=B9+(Jp-Osn/2)*Gs          ! Y coordinate  1st seis--pan 1--rev spd
3510    GOTO 3530
3520    Y2=B5+2*Gs*(Y4+(Pan-2)*(Nvp1-1))      ! Y of 1st seis--panels>1
3530    IF Q7=1 THEN 3550            ! Plot forward-spread FB times only
3540    GOSUB Plot_fbr               ! Plot reverse spread FB times
3550    DUMP GRAPHICS                ! Print out raster display of panel
3560    PLOTTER IS 13,"GRAPHICS"
3570    LOCATE B1,B2,B4,B5           ! Begin succeeding panels
3580    Y1=B5                        ! Starting Y position for next panels
3590  NEXT Pan
3600  EXIT GRAPHICS
3610  PRINT LIN(3)
3620  PRINTER IS 16
3630  G$="N"
3640  INPUT "Do you want to replot FB's? (Y/N--default is N)",G$
3650  IF G$="N" THEN 3670
3660  GOTO 1810
3670  RETURN
3680  !
3690 Print_label:                    ! Print label at top of plot
3700  LORG 6                         ! LORG 6, center and top of letters
3710  ON Q7 GOTO 3720,3740,3760      ! Branches for different labels
3720  B$=" PN  ELEV(m)       FIRST ARRIVAL TIME (FORWARD SPREADS)"
3730  GOTO 3770
3740  B$=" PN  ELEV(m)       FIRST ARRIVAL TIME (REVERSE SPREADS)"
3750  GOTO 3770
3760  B$=" PN  ELEV(m)            FIRST ARRIVAL TIME (ms)"
3770  MOVE B3/2,B7-1
3780  LABEL C$
3790  N$=VAL$(2*Nrec)                ! Number of records
3800  Pnint$=VAL$(Pnint)
3810  D$="PN int = "&Pnint$&"m"&"    Number of records = "&N$
3820  MOVE B3/2,B7-5
3830  LABEL D$
3840  LORG 1                         ! LORG 1, left and bottom of letters
3850  MOVE 0,B7-11
3860  LABEL B$
3870  Botel$=VAL$(Bot_elev)
3880  Topel$=VAL$(Top_elev)
3890  LDIR 270                       ! Rotate lettering
3900  LORG 8
3910  MOVE B1+10,B9+2
3920  LABEL Botel$
3930  MOVE B1+20,B9+2
3940  LABEL Topel$
3950  Nt=(Top_time-Bot_time)/Ti+1
3960  Bott$=VAL$(Bot_time)
3970  MOVE B1+25,B9+2
```

```
3980  LABEL Bott$
3990  Bint=(B2-B1-28)/(Nt-1)
4000  B01=B1+25
4010  FOR K=2 TO Nt
4020    Tlab$=VAL$(Bot_time+(K-1)*Ti)
4030    B01=B01+Bint
4040    MOVE B01,B9+2
4050    LABEL Tlab$
4060  NEXT K
4070  LDIR 0
4080  LORG 3
4090  RETURN
4100  !
4110 Print_pn:                      ! Print PN along edge of plot
4120  Pn$=VAL$(Pn(J1))              ! First PN of the panel
4130  Y2=Y1                         ! Starting Y value
4140  MOVE 0,Y2
4150  LABEL Pn$                     ! Label first PN of the panel
4160  IF Pan>1 THEN 4200
4170  St=1
4180  IF J3<10 THEN 4200
4190  St=2
4200  FOR I=J1+St TO J2 STEP St
4210    Y2=Y2-St*Gs
4220    Pn$=VAL$(Pn(I))
4230    MOVE 0,Y2
4240    LABEL Pn$                   ! Print rest of PN's along edge
4250  NEXT I
4260  RETURN
4270  !
4280 Plot_elev:                     ! Plot elevations
4290  MOVE Elev(J1),Y2
4300  FOR I=J1+1 TO J2
4310    Y2=Y2-Gs
4320    DRAW Elev(I),Y2
4330    DRAW Bot_elev,Y2
4340    DRAW Elev(I),Y2
4350  NEXT I
4360  RETURN
4370  !
4380 Plot_fbf:                      ! Plot first breaks for forward spreads
4390  FOR J=J4 TO J5
4400    Y2=Y2-4*Gs
4410    Y3=Y2
4420    IF Bot_time<>0 THEN 4510
4430    IF Plot=2 THEN 4510
4440    MOVE 0,Y3+Osn/2*Gs
4450    LINE TYPE 1
4460    POLYGON .8
4470    LINE TYPE 3
```

```
4480    DRAW Tp1(J,1),Y3
4490    LINE TYPE 1
4500    GOTO 4520
4510    MOVE Tp1(J,1),Y3
4520    POLYGON Ra
4530    FOR K=2 TO 12
4540      Y3=Y3-Gs
4550      DRAW Tp1(J,K),Y3
4560    NEXT K
4570    MOVE Tp1(J,12),Y3
4580    POLYGON Ra
4590  NEXT J
4600  RETURN
4610  !
4620 Plot_fbr:                          ! Plot first breaks for reverse spreads
4630  FOR J=J4 TO J5
4640    Y2=Y2-Jp*Gs
4650    Y3=Y2+Osn/2*Gs
4660    MOVE Tp2(J,1),Y3
4670    LINE TYPE 1
4680    POLYGON Ra,4,4
4690    IF Q7<>2 THEN 4710
4700    GOTO 4720
4710    LINE TYPE 3
4720    FOR K=2 TO 12
4730      Y3=Y3-Gs
4740      DRAW Tp2(J,K),Y3
4750    NEXT K
4760    MOVE Tp2(J,12),Y3
4770    LINE TYPE 1
4780    POLYGON Ra,4,4
4790    IF Bot_time<>0 THEN 4850
4800    IF Plot=2 THEN 4850
4810    LINE TYPE 3
4820    DRAW 0,Y3-Osn/2*Gs
4830    LINE TYPE 1
4840    POLYGON .8
4850  NEXT J
4860  RETURN
4870  !
```

```
10   PRINT "PROGRAM 'HRCOMP'  LAST REVISION : 10 APR 1990"
20   PRINT "NOTE: Max geophones/spread = 24, and max record pairs = 150"
30   OPTION BASE 1
40   OVERLAP
50   DEG                          ! Set degree mode
60   !
70   GOSUB File_name              ! Enter file names
80   GOSUB Read_fb                ! Read first-break times
90   GOSUB Read_elev              ! Read elevation data
100  GOSUB Tab_in_data            ! Tabulate input data
110  GOSUB Plot_fb_elev           ! Plot first breaks and elevations
120  GOSUB Estab_abc_int          ! Establish ABC intervals
130  GOSUB Velocities             ! Compute and enter velocities
140  GOSUB Comp_abc               ! Compute depths using ABC method
150  GOSUB Plot_final             ! Plot LVL, time to datum, and mean V2
160  GOSUB Tab_results            ! Tabulate results
170  GOSUB Store_td               ! Store time to datum and PN's
180  GOSUB Comp_sc                ! Compute static corrections
190  GOSUB Elev_corr_fb           ! Plot elev-corr FB & comp appar. vel.
200  DISP "PROGRAM COMPLETED"
210  END
220  !
230  DIM B$[80],C$[80],D$[80],Info$[80],Infor$[80]
240  DIM Eavg(150),Maxtf(150),Maxtr(150),Mintf(150),Mintr(150)
250  DIM Tw(150,30),Twx(150),Tw1(30,150),Tw2(30)
260  DIM Vaf(150),Var(150),V1abc(150),V1for(150),V1m(150),V1rev(150),V2m(150)
270  DIM X(24),Y(24),Z(150,30),Zw(150),Z1(30,150),Z2(30)
280  INTEGER P(150,30),Pn(150),Posn(150),Seq(150),Sppn1(150),Sppn2(150)
290  INTEGER Xcf(150),Xcr(150)
300  SHORT Ele(150),Elev(150),Ewx(150),Td(150),Tf(150,24),Tp1(150,24)
310  SHORT Tp2(150,24),Tr(150,24),Tscf(150,24),Tscr(150,24)
320  !
330 Ready:                        ! Ready to proceed
340  G$="Y"
350  INPUT "ARE YOU READY TO PROCEED? (Y/N--default is Y)",G$
360  IF G$="N" THEN 340
370  RETURN
380  !
390 File_name:                    ! Enter file name
400  Q1=1                         ! Q1=1; flag to read/store tape data
410  Q2=1                         ! Q2=1; flag for no elev correction
420  INPUT "Data date (14 char,max):",Data_date$
430  PRINT LIN(1);"ENTER LEAD SYMBOLS FOR 6-CHAR FILE NAMES"
440  INPUT "One-letter area designation; ",B$
450  Y$="9"
460  INPUT "Single number for year (example: 1989=9--default=9)",Y$
470  INPUT "Line number (max=99, if <10, prefix with 0);",L$
480  Na$=B$&Y$&L$
490  Fb$=Na$&"FB"
500  Elev$=Na$&"EL"
```

```
510   PRINT LIN(1);" File name for first break times: ";Fb$
520   PRINT "        File name for elevations: ";Elev$
530   G$="N"
540   INPUT "Do you want to change file names? (Y/N--default is N)",G$
550   IF G$="N" THEN 570
560   GOTO 440
570   Nd=12
580   INPUT "Number of detectors per record (default=12):",Nd
590   PRINT "  Number of detectors per record =";Nd
600   Q5=1                        ! Q5=1; flag to compute total line
610   G$="Y"
620   INPUT "Do you want to compute total line? (Y/N--default is Y)",G$
630   IF G$="Y" THEN 690
640   Q5=2                        ! Q5=2; flag to compute part of line
650   INPUT "Forward SP at which computation are to begin:",Spstart
660   PRINT "    Forward SP at start of comp. =";Spstart
670   INPUT "Forward SP at which computation are to end:",Spend
680   PRINT "Forward SP at end of computations =";Spend
690   RETURN
700   !
710 Read_fb:                      ! Read stored first-break data
720   G$="Y"
730   INPUT "Do you want to read fb data from tape? (Y/N--default is Y)",G$
740   IF G$="Y" THEN 790
750   Q1=2                        ! Q1=2; flag to read data from disk
760   MASS STORAGE IS ":S7"
770   DISP "READING FIRST BREAK DATA FROM DISK"
780   GOTO 840
790   BEEP
800   PRINT LIN(1);"INSERT FIRST BREAK DATA TAPE IN T15"
810   GOSUB Ready                 ! Ready to proceed
820   MASS STORAGE IS ":T15"
830   DISP "READING FIRST BREAK DATA STORED ON TAPE"
840   ASSIGN #2 TO Fb$
850   READ #2;Info$,Pnint,Osn
860   L=LEN(Info$)
870   N2$=Info$[L-2,L]
880   N2=VAL(N2$)                 ! Total number of records along line
890   N1=N2/2                     ! Total number of SP pairs along line
900   REDIM Eavg(N1),Maxtf(N1),Maxtr(N1),Mintf(N1),Mintr(N1),Sppn1(N1),Sppn2(N1)
910   REDIM Tf(N1,Nd),Tp1(N1,Nd),Tp2(N1,Nd),Tr(N1,Nd),Tscf(N1,Nd),Tscr(N1,Nd)
920   REDIM V1for(N1),V1m(N1),V1rev(N1),V2m(N1),Xcf(N1),Xcr(N1)
930   FOR J=1 TO N1
940     READ #2;Sppn1(J),Sppn2(J)
950     FOR K=1 TO Nd
960       READ #2;Tf(J,K),Tr(J,K)
970     NEXT K
980   NEXT J
990   Xc=(Sppn2(1)-Sppn1(1))*Pnint   ! Xc=distance between SP pairs
1000  Jump=Sppn1(2)-Sppn1(1)         ! Jump=spread advance in terms of PN's
```

```
1010  PRINT LIN(1);Info$
1020  PRINT "    Position Number (PN) interval =";Pnint;"m/PN"
1030  PRINT "        Distance between SP pairs =";Xc
1040  Xd=(Xc-Osn*Pnint)/(Nd-1)
1050  PRINT "      Distance between detectors =";Xd
1060  Os=Osn*Pnint/Xd                ! Offset in terms of trace numbers
1070  Jp=Jump*Pnint/Xd               ! Spread advance in terms of trace numbers
1080  PRINT "PN of first forward SP along line =";Sppn1(1)
1090  PRINT " PN of last reverse SP along line =";Sppn2(N1)
1100  N2=(Sppn2(N1)-Sppn1(1))/Jump+1
1110  PRINT "  Total number of SP's along line =";N2
1120  PRINT "  Spread advance in terms of PN's =";Jump
1130  N0=(Sppn2(N1)-Sppn1(1))/2+1    ! Total number of seis along line
1140  REDIM Elev(N0),Ewx(N0),P(N1,Nd+Os),Pn(N0)                       ! REDIM
1150  REDIM Td(N0),Tw(N1,Nd+Os),Tw1(Nd+Os,N0),Tw2(Nd+Os),Twx(N0)      ! REDIM
1160  REDIM Z(N1,Nd+Os),Z1(Nd+Os,N0),Z2(Nd+Os),Zw(N0)                 ! REDIM
1170  PRINT "Total number of detectors on line =";N0
1180  PRINT "          Offset to near detector =";Osn*Pnint;"m"
1190  IF Q5=1 THEN 1280              ! Branch; all stations to be computed
1200  J4=(Spstart-Sppn1(1))/8+1      ! J index of T1(J,K) start times
1210  PRINT "     Number of first record pair =";J4
1220  J5=(Spend-Sppn1(1))/8+1        ! J index of T1(J,K) end times
1230  PRINT "      Number of last record pair =";J5
1240  I1=4*(J4-1)+1                  ! I index for starting elev & PN
1250  I2=4*(J5-1)+1+Nd               ! I index for ending elev & PN
1260  Nsta=I2-I1+1                   ! Number of station to be plotted
1270  GOTO 1320
1280  J4=1                           ! J index of first forward refr. time
1290  J5=N1                          ! J index of last forward refr. time
1300  I1=1                           ! I index of first forward refr. time
1310  I2=N0                          ! I index of last forward refr. time
1320  Nsta=I2-I1+1                   ! Number of station to be plotted
1330  PRINT "Number of stations to be computed =";Nsta
1340  Nr=J5-J4+1                     ! Number of forward records
1350  PRINT Info$
1360  PRINT "Using above information, enter title wanted (72 char, max)"
1370  INPUT "Title:",C$
1380  C$=C$&"   "&Data_date$
1390  PRINT "Title: ";C$
1400  RETURN
1410  !
1420 Read_elev:                      ! Read stored elevation data
1430  G$="Y"
1440  INPUT "Do you want to read elev data from tape? (Y/N--default is Y)",G$
1450  IF G$="Y" THEN 1500
1460  Q1=2                           ! Q1=2; flag to read data from disk
1470  MASS STORAGE IS ":S7"
1480  DISP "READING ELEVATION DATA FROM DISK"
1490  GOTO 1550
1500  BEEP
```

```
1510  PRINT LIN(1);"INSERT ELEVATION DATA TAPE IN T15"
1520  GOSUB Ready                   ! Ready to proceed
1530  MASS STORAGE IS ":T15"
1540  DISP "READING ELEVATION DATA FROM TAPE"
1550  ASSIGN #1 TO Elev$
1560  READ #1;Infor$,Pnint
1570  L=LEN(Infor$)
1580  Nelev$=Infor$[L-2,L]
1590  Nelev=VAL(Nelev$)             ! Number of elevations along line
1600  FOR J=1 TO Nelev
1610    READ #1;Seq(J),Posn(J),Ele(J)
1620  NEXT J
1630  I_elev=(Sppn1(1)-Posn(1))/2   ! Elev index at first forward SP
1640  FOR J=1 TO NO                 ! Re-order elevations and PN's
1650    Elev(J)=Ele(J+I_elev)
1660    Pn(J)=Posn(J+I_elev)
1670  NEXT J
1680  RETURN
1690  !
1700 Tab_in_data:                   ! Tabulate input data
1710  G$="N"
1720  INPUT "Do you want to tabulate input data? (Y/N--default is N)",G$
1730  IF G$="N" THEN 2150
1740  PRINTER IS 0
1750  PRINT LIN(1);Info$
1760  PRINT "First breaks file name: ";Fb$;"      Elevations file name: ";Elev$
1770  IMAGE #,6(4D.D,X,3D.D,X)/
1780  PRINT LIN(1);"ELEV AND FB TIMES FOR TRACES 1 THRU";Nd;"FOR FORWARD SPREADS"
1790  I5=I1-Jp
1800  FOR J=J4 TO J5
1810    Seis1=Sppn1(J)+Osn
1820    Seis12=Sppn2(J)
1830    I5=I5+Jp
1840    I=I5+Osn/2
1850    PRINT "For record from SP";Sppn1(J);" at elev=";Elev(I5);"into spread from PN";Seis1;"to";Seis12
1860    FOR K=1 TO Nd STEP 6
1870      PRINT USING 1770;Elev(I),Tf(J,K),Elev(I+1),Tf(J,K+1),Elev(I+2),Tf(J,K+2),Elev(I+3),Tf(J,K+3),Elev(I+4),Tf(J,K+
4),Elev(I+5),Tf(J,K+5)
1880      I=I+6
1890    NEXT K
1900  NEXT J
1910  PRINT LIN(1);"ELEV AND FB TIMES FOR TRACES 1 THRU";Nd;"FOR REVERSE SPREADS"
1920  I5=(Sppn2(J4)-Jump)/2
1930  I6=(Sppn1(J4)-Jump)/2
1940  FOR J=J4 TO J5
1950    Seis1=Sppn1(J)
1960    Seis12=Seis1+2*(Nd-1)
1970    I5=I5+Jp
1980    I6=I6+Jp
1990    I=I6
```

```
2000    PRINT "For record from SP";Sppn2(J);" at elev=";Elev(I5);"into spread from PN";Seis1;"to";Seis12
2010    FOR K=1 TO Nd STEP 6
2020      PRINT USING 1770;Elev(I),Tr(J,K),Elev(I+1),Tr(J,K+1),Elev(I+2),Tr(J,K+2),Elev(I+3),Tr(J,K+3),Elev(I+4),Tr(J,K+
4),Elev(I+5),Tr(J,K+5)
2030      I=I+6
2040    NEXT K
2050  NEXT J
2060  G$="Y"
2070  INPUT "Are the tabulated data acceptable? (Y/N--default is Y)",G$
2080  IF G$="Y" THEN 2130
2090  BEEP
2100  PRINT LIN(1);"RETURN TO SPECIFIC DATA ENTRY PROGRAM"
2110  PRINT "PROGRAM TERMINATED--INPUT DATA UNACCEPTABLE"
2120  END
2130  PRINT LIN(3)
2140  PRINTER IS 16
2150  RETURN
2160  !
2170 Plot_fb_elev:                   ! Plot first breaks and elevations
2180  RESTORE 2190
2190  DATA 0,123.1,123.1,0,100,72,50
2200  READ B1,B2,B3,B4,B5,B7,B9
2210  B3=B2-B1
2220  IF Q2=2 THEN 2280              ! Branch;plot elev corrected arrivals
2230  G$="Y"
2240  INPUT "Do you want to plot arrivals? (Y/N--default is Y)",G$
2250  IF G$="N" THEN 3970
2260  MAT Tp1=Tf                     ! Plot values = raw TB's, forward spd
2270  MAT Tp2=Tr                     ! Plot values = raw TB's, reverse spd
2280  G$="Y"
2290  Q7=3                           ! Q7=3; flag for forward and reverse
2300  PRINTER IS 16
2310  INPUT "Do you want forward and reverse on same plot? (Y/N--default is Y)",G$
2320  IF G$="Y" THEN 2390
2330  G$="Y"
2340  INPUT "Do you want only the forward results? (Y/N--default is Y)",G$
2350  IF G$="N" THEN 2380
2360  Q7=1                           ! Q7=1; flag for forward-spread plot only
2370  GOTO 2390
2380  Q7=2                           ! Q7=2; flag for reverse-spread plot only
2390  INPUT "Number of values wanted in first panel (must be odd number):",Nvp1
2400  PRINT "           Number of values in first panel =";Nvp1
2410  Nvp2=2*Nvp1-1
2420  Ns=Nvp1-1                      ! Number of spaces in panel no. 1
2430  Ns2=2*Ns                       ! Number of spaces in panels > no. 1
2440  FOR P=1 TO 100
2450    Ns=Ns+Ns2
2460    IF Ns>=Nsta-1 THEN 2480
2470  NEXT P
2480  Npan=P+1
```

```
2490 PRINT "                    Number of panels required =";Npan
2500 Nlast=Nsta-(Ns-2*(Nvp1-1))
2510 PRINT "              Number of values in last panel =";Nlast
2520 IF Npan>=2 THEN 2560
2530 BEEP
2540 PRINT "ERROR: NO. OF PANELS MUST BE >=2. RESELECT NO. OF POINTS--PANEL 1"
2550 GOTO 2390
2560 G$="N"
2570 INPUT "Do you want to change no. of points in panel 1? (Y/N--default is N)",G$
2580 IF G$="N" THEN 2600
2590 GOTO 2390
2600 Ngdu=100*Npan-50              ! Total number of GDU's for all panels
2610 Gs=Ngdu/Ns                    ! Number of GDU's par plot station space
2620 MAT SEARCH Elev(*),MAX;Max_elev
2630 MAT SEARCH Elev(*),MIN;Min_elev
2640 PRINT LIN(1)
2650 IMAGE "Min elev = ",4D.D,"  Max elev = ",4D.D
2660 PRINT USING 2650;Min_elev,Max_elev
2670 Ei=2
2680 INPUT "Elevation increment for plot (default is 2 m):",Ei
2690 MAT Mintf=(9999)
2700 MAT Mintr=(9999)
2710 FOR J=J4 TO J5
2720   FOR K=1 TO Nd
2730     IF Tp1(J,K)=0 THEN Tp1(J,K)=Tp1(J,Nd)
2740     IF Tp2(J,K)=0 THEN Tp2(J,K)=Tp2(J,1)
2750   NEXT K
2760 NEXT J
2770 FOR J=J4 TO J5                ! Determine max and min refraction times
2780   MAT SEARCH Tp1(J,*),MAX;Maxtf(J)
2790   MAT SEARCH Tp1(J,*),MIN;Mintf(J)
2800   MAT SEARCH Tp2(J,*),MAX;Maxtr(J)
2810   MAT SEARCH Tp2(J,*),MIN;Mintr(J)
2820 NEXT J
2830 MAT SEARCH Maxtf(*),MAX;Maxftb
2840 MAT SEARCH Mintf(*),MIN;Minftb
2850 MAT SEARCH Maxtr(*),MAX;Maxrtb
2860 MAT SEARCH Mintr(*),MIN;Minrtb
2870 Maxt=MAX(Maxftb,Maxrtb)
2880 Mint=MIN(Minftb,Minrtb)
2890 PRINT "Maximum arrival time = ";Maxt
2900 PRINT "Minimum arrival time = ";Mint
2910 Ti=10                         ! Establish plot increments
2920 INPUT "FB time increment for plot (default is 10 ms) =",Ti
2930 Top_time=INT(Maxt/Ti)*Ti+Ti   ! Establish top/bottom border values
2940 Bot_time=INT(Mint/Ti)*Ti
2950 Ra=.3*(Top_time-Bot_time)/40
2960 IF Top_time<>Bot_time THEN 2990
2970 Ti=Ti-2
2980 GOTO 2930
```

```
2990 PRINT "Bottom border time is ";Bot_time
3000 IF Q2=2 THEN 3060              ! Branch; plot elev-corrected arrivals
3010 G$="N"
3020 INPUT "Do you want want bottom border time = 0? (Y/N--default is N)",G$
3030 IF G$="Y" THEN 3050
3040 GOTO 3060
3050 Bot_time=0
3060 Top_elev=INT(Max_elev/Ei)*Ei+Ei
3070 Bot_elev=INT(Min_elev/Ei)*Ei
3080 IF Top_elev<>Bot_elev THEN 3110
3090 Ei=Ei-1
3100 GOTO 3060
3110 Elev_int=(Top_elev-Bot_elev)/Ei
3120 Elev_int=10/Elev_int
3130 PRINTER IS 0
3140 PRINT LIN(2)                   ! Paper advance 2 spaces before plotting
3150 PLOTTER IS 13,"GRAPHICS"
3160 GRAPHICS
3170 CLIP B1,B2,B4,B7
3180 GOSUB Print_label              ! Print plot label
3190 J2=I1                          ! Initialization for J1 in 'Pan' loop
3200 Y1=B9                          ! Starting Y value for panel 1
3210 FOR Pan=1 TO Npan              ! Print PN's and plot panel data
3220   J1=J2                        ! J1=index of first value of a panel
3230   IF Pan>1 THEN 3260
3240   J2=J1+Nvp1-1
3250   GOTO 3300
3260   IF Pan=Npan THEN 3290
3270   J2=J1+Nvp2-1                 ! J2=index of last value--interior panel
3280   GOTO 3300
3290   J2=N0                        ! J2=index of last value in last panel
3300   J3=J2-J1+1                   ! J3=number of values within a panel
3310   LDIR 0                       ! Letter direction for PN's
3320   LORG 2                       ! Letter origin for PN's
3330   GOSUB Print_pn               ! Print PN's along edge of panel
3340   IF Pan>1 THEN 3370
3350   CLIP B1+10,B1+20,B4,B9       ! Set up elev frame for panel 1
3360   GOTO 3410
3370   IF Pan=Npan THEN 3400
3380   CLIP B1+10,B1+20,B4,B5       ! Set up elev frame for interior panels
3390   GOTO 3410
3400   CLIP B1+10,B1+20,B5-(N0-J1)*Gs,B5  ! Set up elev frame for last panel
3410   FRAME
3420   GRID Elev_int,B5             ! Plot grid for elevations
3430   IF Pan>1 THEN 3480
3440   LOCATE B1+10,B1+20,B4,B9     ! Plot area for elev for panel 1
3450   SCALE Bot_elev,Top_elev,0,B9 ! Scale for elev for panel 1
3460   Y2=B9
3470   GOTO 3560
3480   IF Pan=Npan THEN 3530
```

```
3490    LOCATE B1+10,B1+20,B4,B5     ! Plot area for elev--interior panels
3500    SCALE Bot_elev,Top_elev,0,B5 ! Scale for elev for interior panels
3510    Y2=B5
3520    GOTO 3560
3530    LOCATE B1+10,B1+20,B5-(NO-J1)*Gs,B5      ! Plot area for last panel
3540    SCALE Bot_elev,Top_elev,B5-(NO-J1)*Gs,B5 ! Scale for elev--last panel
3550    Y2=B5
3560    GOSUB Plot_elev              ! Plot elevations
3570    IF Pan>1 THEN 3600
3580    LOCATE B1+25,B2-3,B4,B9      ! Area for FB's for panel 1
3590    GOTO 3640
3600    IF Pan=Npan THEN 3630
3610    LOCATE B1+25,B2-3,B4,B5      ! Area for FB's for interior panels
3620    GOTO 3640
3630    LOCATE B1+25,B2-3,B5-(NO-J1)*Gs,B5  ! Area for FB's for last panel
3640    FRAME                        ! Frame for FB's
3650    SCALE Bot_time,Top_time,J3-1,0   ! Scale for FB grid
3660    GRID Ti,2                    ! Plot grid for first breaks
3670    IF Pan>1 THEN 3720
3680    SCALE Bot_time,Top_time,0,B9 ! Scale for FB's--panel 1
3690    Y2=B9-(Osn/2-4)*Gs           ! Y coordinate of first seis--panel 1
3700    Y4=Y2/(2*Gs)                 ! Shift number from first panel
3710    GOTO 3770
3720    IF Pan=Npan THEN 3750
3730    SCALE Bot_time,Top_time,0,B5 ! Scale for FB's--interior panels
3740    GOTO 3760
3750    SCALE Bot_time,Top_time,B5-(NO-J1)*Gs,B5   ! Scale for FB's--last panel
3760    Y2=B5+2*Gs*(Y4+(Pan-2)*(Nvp1-1))      ! Y of 1st seis--panels>1
3770    IF Q7=2 THEN 3790            ! Plot reverse-spread FB times only
3780    GOSUB Plot_fbf               ! Plot forward spread FB times
3790    IF Pan>1 THEN 3820
3800    Y2=B9+(Jp-Osn/2)*Gs          ! Y coordinate  1st seis--pan 1--rev spd
3810    GOTO 3830
3820    Y2=B5+2*Gs*(Y4+(Pan-2)*(Nvp1-1))      ! Y of 1st seis--panels>1
3830    IF Q7=1 THEN 3850            ! Plot forward-spread FB times only
3840    GOSUB Plot_fbr               ! Plot reverse spread FB times
3850    DUMP GRAPHICS                ! Print out raster display of panel
3860    PLOTTER IS 13,"GRAPHICS"
3870    LOCATE B1,B2,B4,B5           ! Begin succeeding panels
3880    Y1=B5                        ! Starting Y position for next panels
3890  NEXT Pan
3900  EXIT GRAPHICS
3910  PRINT LIN(3)
3920  PRINTER IS 16
3930  G$="N"
3940  INPUT "Do you want to replot FB's? (Y/N--default is N)",G$
3950  IF G$="N" THEN 3970
3960  GOTO 2280
3970  RETURN
3980  !
```

```
3990 Print_label:                     ! Print label at top of plot
4000  LORG 6                          ! LORG 6, center and top of letters
4010  ON Q7 GOTO 4020,4040,4060       ! Branches for different labels
4020  B$=" PN  ELEV(m)       FIRST ARRIVAL TIME (FORWARD SPREADS)"
4030  GOTO 4070
4040  B$=" PN  ELEV(m)       FIRST ARRIVAL TIME (REVERSE SPREADS)"
4050  GOTO 4070
4060  B$=" PN  ELEV(m)             FIRST ARRIVAL TIME (ms)"
4070  MOVE B3/2,B7-1
4080  LABEL C$
4090  Pnint$=VAL$(Pnint)
4100  D$="PN int = "&Pnint$&"m"&"    Number of records = "&VAL$(2*Nr)
4110  MOVE B3/2,B7-5
4120  LABEL D$
4130  LORG 1                          ! LORG 1, left and bottom of letters
4140  MOVE 0,B7-11
4150  LABEL B$
4160  Botel$=VAL$(Bot_elev)
4170  Topel$=VAL$(Top_elev)
4180  LDIR 270                        ! Rotate lettering
4190  LORG 8
4200  MOVE B1+10,B9+2
4210  LABEL Botel$
4220  MOVE B1+20,B9+2
4230  LABEL Topel$
4240  Nt=(Top_time-Bot_time)/Ti+1
4250  Bott$=VAL$(Bot_time)
4260  MOVE B1+25,B9+2
4270  LABEL Bott$
4280  Bint=(B2-B1-28)/(Nt-1)
4290  B01=B1+25
4300  FOR K=2 TO Nt
4310    Tlab$=VAL$(Bot_time+(K-1)*Ti)
4320    B01=B01+Bint
4330    MOVE B01,B9+2
4340    LABEL Tlab$
4350  NEXT K
4360  LDIR 0
4370  LORG 3
4380  RETURN
4390  !
4400 Print_pn:                        ! Print PN along edge of plot
4410  Pn$=VAL$(Pn(J1))                ! First PN of the panel
4420  Y2=Y1                           ! Starting Y value
4430  MOVE 0,Y2
4440  LABEL Pn$                       ! Label first PN of the panel
4450  IF Pan>1 THEN 4490
4460  St=1
4470  IF J3<10 THEN 4490
4480  St=2
```

```
4490  FOR I=J1+St TO J2 STEP St
4500    Y2=Y2-St*Gs
4510    Pn$=VAL$(Pn(I))
4520    MOVE 0,Y2
4530    LABEL Pn$                   ! Print rest of PN's along edge
4540  NEXT I
4550  RETURN
4560  !
4570 Plot_elev:                     ! Plot elevations
4580  MOVE Elev(J1),Y2
4590  FOR I=J1+1 TO J2
4600    Y2=Y2-Gs
4610    DRAW Elev(I),Y2
4620    DRAW Bot_elev,Y2
4630    DRAW Elev(I),Y2
4640  NEXT I
4650  RETURN
4660  !
4670 Plot_fbf:                      ! Plot first breaks for forward spreads
4680  FOR J=J4 TO J5
4690    Y2=Y2-Jp*Gs
4700    IF Q2=2 THEN 4800           ! Branch; flag for elev_corrected FB's
4710    Y3=Y2
4720    IF Bot_time<>0 THEN 4880
4730    MOVE 0,Y3+Os*Gs
4740    LINE TYPE 1
4750    POLYGON .8
4760    LINE TYPE 3
4770    DRAW Tp1(J,1),Y3
4780    LINE TYPE 1
4790    GOTO 4880                   ! Branch; skip around elev-corr plot
4800    Y3=Y2-(Xcf(J)-1)*Gs         ! Plot elevation corrected FB's
4810    MOVE Tp1(J,Xcf(J)),Y3       ! MOVE to crossover trace position
4820    POLYGON Ra                  ! Draw circle at first trace position
4830    FOR K=Xcf(J)+1 TO Nd
4840      Y3=Y3-Gs
4850      DRAW Tp1(J,K),Y3
4860    NEXT K
4870    GOTO 4940                   ! MOVE to far trace position
4880    MOVE Tp1(J,1),Y3
4890    POLYGON Ra
4900    FOR K=2 TO Nd
4910      Y3=Y3-Gs
4920      DRAW Tp1(J,K),Y3
4930    NEXT K
4940    MOVE Tp1(J,12),Y3
4950    POLYGON Ra
4960  NEXT J
4970  RETURN
4980  !
```

```
4990 Plot_fbr:                          ! Plot first breaks for reverse spreads
5000  FOR J=J4 TO J5
5010    Y2=Y2-Jp*Gs
5020    Y3=Y2+Os*Gs
5030    MOVE Tp2(J,1),Y3
5040    LINE TYPE 1
5050    POLYGON Ra,4,4
5060    IF Q7<>2 THEN 5080
5070    GOTO 5170
5080    LINE TYPE 3
5090    IF Q2=1 THEN 5170               ! Branch; flag for no elev_corrected FB's
5100    FOR K=2 TO Xcr(J)
5110      Y3=Y3-Gs
5120      DRAW Tp2(J,K),Y3
5130    NEXT K
5140    MOVE Tp2(J,K-1),Y3
5150    POLYGON Ra,4,4
5160    GOTO 5290
5170    FOR K=2 TO Nd
5180      Y3=Y3-Gs
5190      DRAW Tp2(J,K),Y3
5200    NEXT K
5210    MOVE Tp2(J,Nd),Y3
5220    LINE TYPE 1
5230    POLYGON Ra,4,4
5240    IF Bot_time<>0 THEN 5290
5250    LINE TYPE 3
5260    DRAW 0,Y3-Os*Gs
5270    LINE TYPE 1
5280    POLYGON .8
5290  NEXT J
5300  RETURN
5310  !
5320 Estab_abc_int:                     ! Establish ABC intervals
5330  PRINTER IS 16                     ! Printout on screen
5340  Q6=1                              ! Flag for no re-selection of intervals
5350  PRINT "ENTER CROSSOVER DISTANCES AS PROMPTED"
5360  PRINT LIN(1);"TRACE NO. FOR 1ST TRACE BEYOND CROSSOVER--FORWARD SPREADS"
5370  FOR J=J4 TO J5
5380    PRINT "For record";J;"from SP";Sppn1(J);" trace number:";
5390    INPUT Xcf(J)
5400    PRINT Xcf(J)
5410  NEXT J
5420  G$="N"
5430  INPUT "Do you want to change a forward crossover trace? (Y/N--default is N)",G$
5440  IF G$="N" THEN 5500
5450  INPUT "Number of record pair requiring change:",J
5460  PRINT "For record";J;"from SP";Sppn1(J);" trace number:";
5470  PRINT Xcf(J)
5480  PRINT Xcf(J)
```

```
5490  GOTO 5420
5500  IF Q6=2 THEN 5570               ! Branch for re-selection
5510  PRINT LIN(1);"TRACE NO. FOR 1ST TRACE BEYOND CROSSOVER--REVERSE SPREADS"
5520  FOR J=J4 TO J5
5530    PRINT "For record";J;"from SP";Sppn2(J);" trace number:";
5540    INPUT Xcr(J)
5550    PRINT Xcr(J)
5560  NEXT J
5570  G$="N"
5580  INPUT "Do you want to change a reverse crossover trace? (Y/N--default is N)",G$
5590  IF G$="N" THEN 5650
5600  INPUT "Number of record pair requiring change:",J
5610  PRINT "For record";J;"from SP";Sppn2(J);" trace number:";
5620  INPUT Xcr(J)
5630  PRINT Xcr(J)
5640  GOTO 5570
5650  FOR J=J4 TO J5-1               ! Test on selected ABC intervals
5660    IF Xcr(J)-Xcf(J+1)>=Jp THEN 5740
5670    BEEP
5680    PRINT "GAP IN ABC INTERVALS BETWEEN PAIRS";J;"AND";J+1;"OF TOTAL SET"
5690    G$="Y"
5700    INPUT "Do you want to re-select ABC intervals? (Y/N--default is Y)",G$
5710    IF G$="N" THEN 5740
5720    Q6=2                          ! Flag to re-select ABC interval
5730    GOTO 5420
5740  NEXT J
5750  RETURN
5760  !
5770 Velocities:                      ! Compute and enter velocities
5780  IF Q2=2 THEN 6220               ! Branch for elev-corrected FB's
5790  PRINTER IS 16                   ! Printout on screen
5800  G$="N"
5810  INPUT "Do you want hard copy of V1 velocities? (Y/N--default is N)",G$
5820  IF G$="N" THEN 5840
5830  PRINTER IS 0                    ! Hard copy using internal printer
5840  V1f=0
5850  FOR J=J4 TO J5                  ! Compute V1 for forward spreads
5860    IF Xcf(J)>1 THEN 5890
5870    V1for(J)=Osn*Pnint/Tf(J,1)
5880    GOTO 5900
5890    V1for(J)=((Xcf(J)-2)*Xd+Osn*Pnint)/Tf(J,Xcf(J)-1)
5900    V1f=V1f+V1for(J)
5910  NEXT J
5920  V1f=V1f/Nr                      ! Average vel of 1st layer, forward spread
5930  IMAGE "        Average V1 for forward spreads =",D.2D
5940  PRINT USING 5930;V1f
5950  V1r=0
5960  FOR J=J4 TO J5                  ! Compute V1 for reverse spreads
5970    IF Xcr(J)<Nd-1 THEN 6000
5980    V1rev(J)=Osn*Pnint/Tr(J,Nd)
```

```
5990   GOTO 6010
6000   V1rev(J)=((Nd-Xcr(J)-1)*Xd+Osn*Pnint)/Tr(J,Xcr(J)+1)
6010   V1r=V1r+V1rev(J)
6020 NEXT J
6030 V1r=V1r/Nr                        ! Average vel of 1st layer, reverse spread
6040 IMAGE "        Average V1 for reverse spreads =",D.2D
6050 PRINT USING 6040;V1r
6060 V1_avg=.5*(V1f+V1r)
6070 IMAGE "Avg V1 for forward and reverse spreads =",D.2D
6080 PRINT USING 6070;V1_avg
6090 G$="N"
6100 INPUT "Do you want to use overall average V1? (Y/N--default is N)",G$
6110 IF G$="N" THEN 6140
6120 MAT V1m=(V1_avg)
6130 GOTO 6220
6140 V1abc(J4)=(V1for(J4+1)+V1for(J4+2))/2
6150 V1abc(J4+1)=(V1for(J4+2)+V1for(J4+3)+V1rev(J4))/3
6160 FOR J=J4+2 TO J5-2
6170   V1abc(J)=(V1for(J+1)+V1for(J+2)+V1rev(J-1)+V1rev(J-2))/4
6180 NEXT J
6190 V1abc(J5-1)=(V1for(J5)+V1rev(J5-2)+V1rev(J5-3))/3
6200 V1abc(J5)=(V1rev(J5-1)+V1rev(J5-2))/2
6210 MAT V1m=V1abc                     ! Rename for later caluclations
6220 PRINT LIN(1);"         ABC INTERVALS AND FIRST-LAYER VELOCITIES"
6230 PRINT "REC PAIR      FORWARD SPREADS        REVERSE SPREADS    V1abc"
6240 IMAGE 3X,2D,7X,"SP",3D," TR",3D,"  =",D.2D,5X,"SP",3D," TR",3D,"  =",D.2D,"   ",D.DD
6250 FOR J=J4 TO J5                    ! FOR number of paired records
6260   PRINT USING 6240;J,Sppn1(J),Xcf(J),V1for(J),Sppn2(J),Xcr(J),V1rev(J),V1m(J)
6270 NEXT J
6280 PRINTER IS 16                     ! Screen display of V2 velocities
6290 G$="N"
6300 INPUT "Do you want hard copy of V2's? (Y/N--default is N)",G$
6310 IF G$="N" THEN 6330
6320 PRINTER IS 0                      ! Hard copy using internal printer
6330 IF Q2=1 THEN 6360                 ! Branch when using observed FB's
6340 PRINT LIN(1);"LEAST-SQUARE APPARENT VEL WITHIN ABC INTERVALS USING ELEV-CORRECTED FB'S"
6350 GOTO 6370                         ! Skip around next line
6360 PRINT LIN(1);"LEAST-SQUARE APPARENT VEL WITHIN ABC INTERVALS USING OBSERVED FB'S"
6370 PRINT "Record Pair  Forward SP, and Va   Reverse SP, and Va   For/Rev Mean Va"
6380 IMAGE 2X,3D,10X,3D,7X,2D.2D,6X,3D,7X,2D.2D,8X,2D.2D
6390 Vave=0
6400 FOR J=J4 TO J5
6410   X0=(Os+Xcf(J)-2)*Xd
6420   X1=X2=Y1=Y2=Z=0                 ! Initialization of loop
6430   C=0                             ! Initiate count for number of seis
6440   FOR K=Xcf(J) TO Xcr(J)-Os       ! Comp for forward spread
6450     C=C+1
6460     X0=X0+Xd
6470     X(K)=X0                       ! Distance from Jth SP to Kth seis
6480     X1=X1+X(K)                    ! Sum of X values
```

```
6490      IF Q2=1 THEN 6520           ! Branch for observed FB's
6500      Y(K)=Tp1(J,K)               ! Time from Jth SP to Kth seis
6510      GOTO 6530
6520      Y(K)=Tf(J,K)                ! Time from Jth SP to Kth seis
6530      Y1=Y(K)+Y1                  ! Sum of forward FB times
6540      X2=X2+X(K)*X(K)             ! Sum of X-square values
6550      Y2=Y2+Y(K)*Y(K)             ! Sum of Y-square values
6560      Z=Z+X(K)*Y(K)               ! Sum of XY values
6570    NEXT K
6580    X1=X1/C                       ! Mean value of X's
6590    Y1=Y1/C                       ! Mean value of Y's
6600    Vaf(J)=(X2-C*X1*X1)/(Z-C*X1*Y1)  ! Apparent velocity, forward spread
6610    X0=(Os+Nd-Xcf(J))*Xd
6620    X1=X2=Y1=Y2=Z=0               ! Initialization of loop
6630    C=0                           ! Initialize counter
6640    FOR K=Xcf(J)+Os TO Xcr(J)
6650      C=C+1
6660      X0=X0-Xd
6670      X(K)=X0                     ! Distance from Jth SP to Kth seis
6680      X1=X1+X(K)                  ! Sum of reverse spread offsets
6690      IF Q2=1 THEN 6720           ! Branch using observed times
6700      Y(K)=Tp2(J,K)               ! Using elev-corrected times
6710      GOTO 6730                   ! Skip around next line
6720      Y(K)=Tr(J,K)                ! Time to Jth SP to Kth seis
6730      Y1=Y(K)+Y1                  ! Sum of reverse FB times
6740      X2=X2+X(K)*X(K)             ! Sum of X-square values
6750      Y2=Y2+Y(K)*Y(K)             ! Sum of Y-square values
6760      Z=Z+X(K)*Y(K)               ! Sum of XY values
6770    NEXT K
6780    X1=X1/C                       ! Mean value of X's
6790    Y1=Y1/C                       ! Mean value of Y's
6800    Var(J)=(X2-C*X1*X1)/(Z-C*X1*Y1)   ! Apparent velocity, reverse spread
6810    V2m(J)=2*Vaf(J)*Var(J)/(Vaf(J)+Var(J))    ! Mean V2 w/i ABC interval
6820    PRINT USING 6380;J,Sppn1(J),Vaf(J),Sppn2(J),Var(J),V2m(J)
6830    Vave=Vave+V2m(J)
6840  NEXT J
6850  IMAGE "All-record average forward/reverse least square velocity = ",D.2D," m/ms"
6860  V2_avg=Vave/Nr
6870  PRINT USING 6850;V2_avg
6880  RETURN
6890  !
6900 Comp_abc:                        ! Compute depths using ABC method
6910  MAT Z=(999)
6920  FOR J=J4 TO J5
6930    A12=ASN(V1m(J)/V2m(J))        ! Critical angle within ABC interval
6940    C12=COS(A12)                  ! Cosine of critical angle
6950    K1=.5*V1m(J)/C12
6960    K2=Osn-2                      ! Compute PN for traces 1 thru Nd
6970    FOR K=1 TO Nd+Os
6980      K2=K2+2
```

```
6990      P(J,K)=Sppn1(J)+K2
7000    NEXT K
7010    Tc=.5*(Tf(J,Nd)+Tr(J,1))          ! Tc=reciprocal time
7020    IF Xcr(J)-Os>=Xcf(J) THEN 7040
7030    GOTO 7090
7040    FOR K=Xcf(J) TO Xcr(J)-Os         ! Within ABC interval
7050      Tabc=Tf(J,K)+Tr(J,K+Os)-Tc
7060      Z(J,K+Os)=K1*Tabc               ! LVL thickness
7070      Tw(J,K+Os)=Z(J,K+Os)/V1m(J)     ! Time within LVL
7080    NEXT K
7090  NEXT J
7100  Nb=Xcf(J4)+Os                 ! For detectors at beginning of line
7110  A12=ASN(V1m(J4)/V2m(J4))      ! Critical angle near beginning
7120  C12=COS(A12)                  ! Cosine of above critical angle
7130  K1b=.5*V1m(J4)/C12
7140  L=J4
7150  Zfirst=Z(J4,Nb)
7160  FOR K=1 TO Nb-Os
7170    Z(L,K)=(Tr(L,K)-Tr(L,Nb)-(Nb-K)*Xd/V2m(J4))*2*K1b+Zfirst
7180    Tw(L,K)=Z(L,K)/V1m(J4)
7190  NEXT K
7200  Nb=Xcr(J5)-Os                 ! For detectors at end of line
7210  Zlast=Z(J5,Nb+Os)
7220  L=0
7230  FOR K=Nb+Os TO Nd
7240    L=L+1
7250    Z(J5,K+Os)=(Tf(J5,K)-Tf(J5,Nb)-L*Xd/V2m(J5))*2*K1+Zlast
7260    Tw(J5,K+Os)=Z(J5,K+Os)/V1m(J5)
7270  NEXT K
7280  G$="Y"
7290  INPUT "Do you want to tabulate LVL depths and times? (Y/N--default is Y)",G$
7300  IF G$="N" THEN 7540
7310  PRINTER IS 16                 ! Printout on screen
7320  G$="N"
7330  INPUT "Do you want hard copy? (Y/N--default is N)",G$
7340  IF G$="N" THEN 7360
7350  PRINTER IS 0                  ! Harc copy using internal printer
7360  IMAGE "SP ",3D," TRACE",3D,24X,"PN ",3D,"  LVL DEPTH",3D.D,"  LVL TIME",3D.D
7370  PRINT LIN(1);"FOR DETECTORS AT BEGINNING OF LINE"
7380  FOR K=1 TO Xcf(J4)
7390    PRINT USING 7360;Sppn2(J4),K,2*K-1,Z(J4,K),Tw(J4,K)
7400  NEXT K
7410  PRINT LIN(1);"RESULTS OF ABC COMPUTATION"
7420  PRINT "Forward and Reverse SP, Record Trace, Detector PN, LVL Depth, and LVL time"
7430  IMAGE "SP ",3D," TRACE",3D,"    SP ",3D," TRACE",3D,"     PN ",3D,"  LVL DEPTH",3D.D,"  LVL TIME",3D.D
7440  FOR J=J4 TO J5
7450    PRINT LIN(1);
7460    FOR K=Xcf(J) TO Xcr(J)-Os
7470      PRINT USING 7430;Sppn1(J),K,Sppn2(J),K+Os,P(J,K),Z(J,K+Os),Tw(J,K+Os)
7480    NEXT K
```

```
7490  NEXT J
7500  PRINT LIN(1);"FOR DETECTORS AT END OF LINE"
7510  FOR K=Xcr(J5) TO Nd
7520    PRINT USING 7360;Sppn1(J5),K,P(J5,K),Z(J5,K+Os),Tw(J5,K+Os)
7530  NEXT K
7540  MAT Z1=(999)                  ! Combine
7550  FOR J=J4 TO J5
7560    FOR K=1 TO Nd+Os
7570      N=(P(J,K)+1)/2-Os
7580      IF Z(J,K)=999 THEN 7610
7590      Z1(K,N)=Z(J,K)
7600      Tw1(K,N)=Tw(J,K)
7610    NEXT K
7620  NEXT J
7630  FOR M=I1 TO I2                ! Combine duplicate location depths
7640    C=0
7650    MAT Z2=ZER
7660    MAT Tw2=ZER
7670    FOR K=1 TO Nd+Os
7680      IF Z1(K,M)=999 THEN 7720
7690      C=C+1
7700      Z2(C)=Z1(K,M)
7710      Tw2(C)=Tw1(K,M)
7720    NEXT K
7730    IF C<>0 THEN 7770           ! Branch; no missing values at a station
7740    Zw(M)=Zw(M-1)               ! Set missing value = to previous value
7750    Twx(M)=Twx(M-1)             ! Set missing value = to previous value
7760    GOTO 7790
7770    Zw(M)=SUM(Z2)/C
7780    Twx(M)=SUM(Tw2)/C
7790  NEXT M
7800  RETURN
7810  !
7820 Plot_final:                    ! Plot LVL, time to datum, and mean V2
7830  PRINTER IS 16                 ! Printout on screen
7840  RESTORE 7850
7850  DATA 121,10,40,50,80,90       ! Establish borders in GDU's
7860  READ B2,B10,B12,B13,B15,B16
7870  PRINT LIN(1);"FOR PLOT OF LVL, DATUM TIME, AND MEAN V2 VELOCITY"
7880  J1=J4                         ! J index of first forward refr. time
7890  Nsta=I2-I1+1                  ! Number of stations to be plotted
7900  PRINT "Number of detector positions to be plotted =";Nsta
7910  INPUT "Number of values wanted in first panel (must be odd number):",Nvp1
7920  PRINT "             Number of values in first panel =";Nvp1
7930  Nvp2=2*Nvp1-1
7940  Ns=Nvp1-1                     ! Number of spaces in panel no. 1
7950  Ns2=2*Ns                      ! Number of spaces in panels > no. 1
7960  FOR P=1 TO 100
7970    Ns=Ns+Ns2
7980    IF Ns>=Nsta-1 THEN 8000
```

```
7990 NEXT P
8000 Npan=P+1
8010 PRINT "                Number of panels required =";Npan
8020 Nlast=Nsta-(Ns-2*(Nvp1-1))
8030 PRINT "            Number of values in last panel =";Nlast
8040 IF Npan>=2 THEN 8080
8050 BEEP
8060 PRINT "ERROR: NUMBER OF PANELS MUST BE >=2. RESELECT NO. OF POINTS IN PANEL 1"
8070 GOTO 7910
8080 G$="N"
8090 INPUT "Do you want to change number of points in panel 1? (Y/N--default is N)",G$
8100 IF G$="N" THEN 8120
8110 GOTO 7910
8120 Gs=(100*Npan-50)/Ns            ! Number of GDU's per plot station space
8130 MAT Ewx=(9999)
8140 FOR M=I1 TO I2                 ! FOR number of stations along line
8150   Ewx(M)=Elev(M)-Zw(M)         ! Compute elev at base of LVL
8160 NEXT M
8170 MAT SEARCH Ewx(*),MIN;Min_elev_wx   ! Find min elev at base of LVL
8180 PRINT "  Minimum elev at base of LVL =";Min_elev_wx
8190 INPUT "Wanted elevation of fixed datum:",Ed
8200 PRINT " Selected elev of fixed datum =";Ed
8210 INPUT "Wanted elevation at base of elev plot:",Bot_e
8220 PRINT "    Selected bottom elevation =";Bot_e
8230 MAT SEARCH Elev(*),MAX;Min_elev     ! Find maximum elev along traverse
8240 Emax=Min_elev2
8250 FOR J=I1 TO I2
8260   IF Elev(J)<Emax THEN 8280
8270   Emax=Elev(J)
8280 NEXT J
8290 Max_elev=Emax
8300 PRINT "  Maximum elev along traverse =";Max_elev
8310 INPUT "Wanted elevation at top of elev plot:",Top_e
8320 PRINT "       Selected top elevation =";Top_e
8330 Ei=2                                                          ! DEFAULT
8340 INPUT "Increment for elevation grid (default = 2 m):",Ei
8350 PRINT " Selected incr. for elev grid =";Ei
8360 IF Top_e<>Bot_e THEN 8400
8370 BEEP
8380 PRINT "Re-select elevation limits on plot--too close"
8390 GOTO 8210
8400 E_int=(Top_e-Bot_e)/Ei         ! Establish grid interval for elevations
8410 E_int=(B12-B10)/E_int
8420 Td1=Twx(I1)+(Ewx(I1)-Ed)/V2_avg
8430 MAT Td=(Td1)
8440 FOR M=I1 TO I2                 ! FOR number of stations along line
8450   Td(M)=Twx(M)+(Ewx(M)-Ed)/V2_avg          ! Compute time to datum
8460 NEXT M
8470 MAT SEARCH Td(*),MIN;Min_td    ! Find minimum time to datum
8480 MAT SEARCH Td(*),MAX;Max_td    ! Find maximum time to datum
```

```
8490 IMAGE "Minimum time to datum =",3D.D,"  Maximum time to datum =",3D.D
8500 PRINT USING 8490;Min_td,Max_td
8510 INPUT "Wanted bottom datum time on plot:",Bot_t
8520 PRINT "   Selected bottom datum time =";Bot_t
8530 INPUT "Wanted top datum time on plot:",Top_t
8540 PRINT "      Selected top datum time =";Top_t
8550 Ti=5                                                      ! DEFAULT
8560 INPUT "Increment for datum time grid (default=5 ms):",Ti
8570 PRINT "   Selected incr. for Td grid =";Ti
8580 IF Top_t<>Bot_t THEN 8600
8590 GOTO 8510
8600 FOR J=1 TO N1                  ! Minimum V2 when partial section
8610   IF V2m(J)=0 THEN V2m(J)=V2m(J5)
8620 NEXT J
8630 MAT SEARCH V2m(*),MIN;Minv     ! Find minimum V2
8640 MAT SEARCH V2m(*),MAX;Maxv     ! Find maximum V2
8650 IMAGE "Minimum V2 =",2D.2D,"  Maximum V2 =",2D.2D
8660 PRINT USING 8650;Minv,Maxv
8670 INPUT "Wanted bottom mean V2:",Bot_v
8680 PRINT "      Selected bottom mean V2 =";Bot_v
8690 INPUT "Wanted top mean V2:",Top_v
8700 PRINT "         Selected top mean V2 =";Top_v
8710 Vi=.1                                                     ! DEFAULT
8720 INPUT "Increment for mean V2 grid (default is 0.1 m/ms) =",Vi
8730 PRINT "   Selected incr. for V2 grid =";Vi
8740 IF Top_v<>Bot_v THEN 8760
8750 GOTO 8670
8760 Ra=.1*Vi                      ! Establish radius of plot circle
8770 PRINT "        Radius of plot circle =";Ra;"in GDU's"
8780 PRINTER IS 0                   ! Hard copy of plot
8790 PRINT LIN(2)                   ! Paper advance 2 spaces before plotting
8800 PLOTTER IS 13,"GRAPHICS"
8810 GRAPHICS
8820 CLIP B1,B2,B4,B7
8830 GOSUB Print_label2             ! Print plot label
8840 J2=I1                          ! Initialization for J1 in 'Pan' loop
8850 Y1=B9                          ! Starting Y value for panel 1
8860 FOR Pan=1 TO Npan              ! Print PN's and plot panel data
8870   J1=J2                        ! J1=index of first value of a panel
8880   IF Pan>1 THEN 8910
8890   J2=J1+Nvp1-1
8900   GOTO 8950
8910   IF Pan=Npan THEN 8940
8920   J2=J1+Nvp2-1                 ! J2=index of last value--interior panel
8930   GOTO 8950
8940   J2=N0                        ! J2=index of last value in last panel
8950   J3=J2-J1+1                   ! J3=number of values within a panel
8960   LDIR 0                       ! Letter direction for PN's
8970   LORG 2                       ! Letter origin for PN's
8980   GOSUB Print_pn               ! Print PN's along edge of panel
```

```
8990    IF Pan>1 THEN 9050              ! Branch when not first panel
9000    LOCATE B10,B12,B4,B9            ! Set up FRAME for first panel
9010    SCALE B10,B12,B4,B9             ! SCALE for GRID
9020    FRAME                           ! FRAME for first panel
9030    GRID E_int,B5,B10,B9            ! GRID for first panel
9040    GOTO 9150                       ! GOTO plot routine
9050    IF Pan=Npan THEN 9110           ! Branch to last panel FRAME set up
9060    LOCATE B10,B12,B4,B5            ! Set up FRAME for interior panels
9070    SCALE B10,B12,B4,B5             ! SCALE for GRID
9080    FRAME                           ! FRAME for interior panels
9090    GRID E_int,B5,B10,B5            ! GRID for interior panels
9100    GOTO 9150                       ! GOTO plot routine
9110    LOCATE B10,B12,B5-(N0-J1)*Gs,B5        ! Set up FRAME for last panel
9120    SCALE B10,B12,B5-(N0-J1)*Gs,B5         ! GRID SCALE for last panel
9130    FRAME                           ! FRAME for last panel
9140    GRID E_int,B5,B10,B5            ! Plot grid for elev/LVL (UDU's)
9150    IF Pan>1 THEN 9200              ! Branch to last-panel test
9160    LOCATE B10,B12,B4,B9            ! Plot area for elev/LVL for panel 1
9170    SCALE Bot_e,Top_e,0,B9          ! Scale for elev/LVL for panel 1
9180    Y2=B9                           ! Y2 set to middle of screen
9190    GOTO 9280                       ! GOTO Plot elev/LVL subroutine
9200    IF Pan=Npan THEN 9250           ! Branch to set up plot area of last pan
9210    LOCATE B10,B12,B4,B5            ! Plot area for elev/LVL--interior panels
9220    SCALE Bot_e,Top_e,0,B5          ! Scale for elev/LVL for interior panels
9230    Y2=B5                           ! Y2 set to top of screen
9240    GOTO 9280                       ! GOTO Plot elev/LVL subroutine
9250    LOCATE B10,B12,B5-(N0-J1)*Gs,B5         ! Plot area for last panel
9260    SCALE Bot_e,Top_e,B5-(N0-J1)*Gs,B5     ! Scale for elev/LVL--last panel
9270    Y2=B5                           ! Y2 set to top of screen
9280    GOSUB Plot_wx                   ! Plot elevations and LVL
9290    IF Pan>1 THEN 9350              ! Branch when not first panel
9300    LOCATE B13,B15,B4,B9            ! Set up FRAME for first panel
9310    FRAME                           ! FRAME first panel
9320    SCALE Bot_t,Top_t,0,J3-1        ! GRID SCALE for datum times
9330    GRID Ti,2                       ! GRID  first panel
9340    GOTO 9450                       ! GOTO plot Td
9350    IF Pan=Npan THEN 9410           ! Branch to last panel FRAME setup
9360    LOCATE B13,B15,B4,B5            ! Set up FRAME for interior panels
9370    FRAME                           ! FRAME interior panels
9380    SCALE Bot_t,Top_t,0,J3-1        ! GRID SCALE for datum times
9390    GRID Ti,2                       ! GRID for interior panels
9400    GOTO 9450                       ! GOTO plot Td
9410    LOCATE B13,B15,B5-(N0-J1)*Gs,B5      ! Set up FRAME for last panel
9420    FRAME                           ! FRAME last panel
9430    SCALE Bot_t,Top_t,0,J3-1        ! GRID SCALE for datum times
9440    GRID Ti,2                       ! GRID  last panel
9450    IF Pan>1 THEN 9500              ! Branch when not first panel
9460    LOCATE B13,B15,B4,B9            ! Plot area for first panel
9470    SCALE Bot_t,Top_t,0,B9          ! Scale for TD's--first panel=pan 1
9480    Y2=B9                           ! Y2 set to middle of screen--panel 1
```

```
9490    GOTO 9580                   ! GOTO Plot datum time subroutine
9500    IF Pan=Npan THEN 9550       ! Branch to last panel plot
9510    LOCATE B13,B15,B4,B5        ! Plot area for interior panels
9520    SCALE Bot_t,Top_t,0,B5      ! Scale for TD's--interior panels
9530    Y2=B5                       ! Y2 set to top of screen
9540    GOTO 9580                   ! GOTO Plot datum time subroutine
9550    LOCATE B13,B15,B5-(N0-J1)*Gs,B5        ! Plot area for last panel
9560    SCALE Bot_t,Top_t,B5-(N0-J1)*Gs,B5     ! Scale for TD's--last panel
9570    Y2=B5                       ! Y2 set to top of screen
9580    GOSUB Plot_datum_time       ! Plot time to datum
9590    IF Pan>1 THEN 9650          ! Branch when not first panel
9600    LOCATE B16,B2,B4,B9         ! Set up FRAME for first panel
9610    FRAME                       ! FRAME first panel
9620    SCALE Bot_v,Top_v,0,J3-1    ! GRID SCALE for velocities
9630    GRID Vi,2                   ! GRID  first panel
9640    GOTO 9750                   ! GOTO plot vel routine
9650    IF Pan=Npan THEN 9710       ! Branch for last panel
9660    LOCATE B16,B2,B4,B5         ! Set up FRAME for interior panels
9670    FRAME                       ! FRAME interior panels
9680    SCALE Bot_v,Top_v,0,J3-1    ! GRID SCALE for velocities
9690    GRID Vi,2                   ! GRID  interior panels
9700    GOTO 9750                   ! GOTO plot vel routine
9710    LOCATE B16,B2,B5-(N0-J1)*Gs,B5        ! Set up FRAME for last panel
9720    FRAME                       ! FRAME last panel
9730    SCALE Bot_v,Top_v,0,J3-1    ! GRID SCALE for velocities
9740    GRID Vi,2                   ! GRID  last panel
9750    IF Pan>1 THEN 9810          ! Branch when not first panel
9760    LOCATE B16,B2,B4,B9         ! Plot area for first panel=panel 1
9770    SCALE Bot_v,Top_v,0,B9      ! Scale for vel for panel 1
9780    Y2=B9-(Os-Jp)*Gs            ! Y coordinate of first seis--panel 1
9790    Y4=Y2/(2*Gs)                ! Shift number from first panel
9800    GOTO 9890                   ! GOTO Plot_vel subroutine
9810    IF Pan=Npan THEN 9860       ! Branch for last panel
9820    LOCATE B16,B2,B4,B5         ! Plot area for interior panels
9830    SCALE Bot_v,Top_v,0,B5      ! Scale for vel for interior panels
9840    Y2=B5+2*Gs*(Y4+(Pan-2)*(Nvp1-1))      ! Y of 1st seis--panels>1
9850    GOTO 9890                   ! GOTO Plot_vel subroutine
9860    LOCATE B16,B2,B5-(N0-J1)*Gs,B5           ! Plot area for last panel
9870    SCALE Bot_v,Top_v,B5-(N0-J1)*Gs,B5    ! Scale for vel--last panel
9880    Y2=B5+2*Gs*(Y4+(Pan-2)*(Nvp1-1))      ! Y of 1st seis--last panel
9890    GOSUB Plot_vel              ! Plot mean V2
9900    DUMP GRAPHICS               ! Print out raster display of panel
9910    PLOTTER IS 13,"GRAPHICS"
9920    LOCATE B1,B2,B4,B5          ! Begin succeeding panels
9930    Y1=B5                       ! Starting Y position for next panels
9940  NEXT Pan
9950  EXIT GRAPHICS
9960  PRINT LIN(3)
9970  PRINTER IS 16
9980  G$="N"
```

```
9990  INPUT "Do you want to replot? (Y/N--default is N)",G$
10000 IF G$="N" THEN 10020
10010 GOTO 7900
10020 RETURN
10030 !
10040 Print_label2:                ! Label for 1st layer,statics, and vel
10050 LORG 6                       ! LORG 6, center and top of letters
10060 B$=" PN      ELEV(m)        TIME TO DATUM(ms)   MEAN V2 VELOCITY"
10070 MOVE B3/2,B7-1
10080 LABEL C$                     ! LABEL top line
10090 Pnint$=VAL$(Pnint)           ! PN interval
10100 D$="PN int = "&Pnint$&"m"&"    Number of records ="&VAL$(2*Nr)&"  Ed ="&VAL$(Ed)
10110 MOVE B3/2,B7-5
10120 LABEL D$                     ! LABEL 2nd line
10130 LORG 1                       ! LORG 1, left and bottom of letters
10140 MOVE 0,B7-11
10150 LABEL B$                     ! LABEL 3rd line
10160 Botel$=VAL$(Bot_e)
10170 Ne=INT((Top_e-Bot_e)/Ei+1)
10180 LDIR 270                     ! Rotate lettering
10190 LORG 8
10200 MOVE B10,B9+2
10210 LABEL Botel$                 ! Label elevations
10220 Bint=(B12-B10)/(Ne-1)
10230 B01=B10
10240 FOR K=2 TO Ne
10250   Tlab$=VAL$(Bot_e+(K-1)*Ei)
10260   B01=B01+Bint
10270   MOVE B01,B9+2
10280   LABEL Tlab$
10290 NEXT K
10300 Nt=INT((Top_t-Bot_t)/Ti+1)     ! Label time to datum
10310 Bott$=VAL$(Bot_t)
10320 MOVE B13,B9+2
10330 LABEL Bott$
10340 Bint=(B15-B13)/(Nt-1)
10350 B01=B13
10360 FOR K=2 TO Nt
10370   Tlab$=VAL$(Bot_t+(K-1)*Ti)
10380   B01=B01+Bint
10390   MOVE B01,B9+2
10400   LABEL Tlab$
10410 NEXT K
10420 Nv=INT((Top_v-Bot_v)/Vi+1)     ! Label mean V2
10430 Botv$=VAL$(Bot_v)
10440 MOVE B16,B9+2
10450 LABEL Botv$
10460 Bint=(B2-B16)/(Nv-1)
10470 B01=B16
10480 FOR K=2 TO Nv
```

```
10490   Vlab$=VAL$(Bot_v+(K-1)*Vi)
10500   B01=B01+Bint
10510   MOVE B01,B9+2
10520   LABEL Vlab$
10530 NEXT K
10540 LDIR 0
10550 LORG 3
10560 RETURN
10570 !
10580 Plot_wx:                      ! Sub: plot elev and base of LVL
10590 MOVE Elev(J1),Y2
10600 FOR I=J1+1 TO J2
10610   Y2=Y2-Gs
10620   DRAW Elev(I),Y2             ! Line to next surface elevation
10630   DRAW Ewx(I),Y2              ! Line from surface to base of 1st layer
10640   DRAW Ewx(I-1),Y2+Gs         ! Back one position along base 1st layer
10650   MOVE Elev(I),Y2             ! MOVE back to surface
10660 NEXT I
10670 RETURN
10680 !
10690 Plot_datum_time:              ! Sub: plot time to fixed datum
10700 MOVE Td(J1),Y2
10710 FOR I=J1+1 TO J2
10720   Y2=Y2-Gs
10730   DRAW Td(I),Y2               ! Line to next time to datum
10740 NEXT I
10750 RETURN
10760 !
10770 Plot_vel:                     ! Sub: plot mean V2
10780 FOR I=J4 TO J5                ! FOR number of pairs
10790   Y2=Y2-Jp*Gs
10800   Y3=Y2-(Xcf(I)-1)*Gs         ! Crossover point on forward spread
10810   MOVE V2m(I),Y3              ! MOVE to start of ABC interval
10820   POLYGON Ra                  ! Draw circle at start of ABC interval
10830   DRAW V2m(I),Y3-(Xcr(I)-Xcf(I)-Os)*Gs
10840   POLYGON Ra                  ! Draw circle at end of ABC interval
10850 NEXT I
10860 RETURN
10870 !
10880 Tab_results:                  ! Tabulate results
10890 G$="N"
10900 INPUT "Do you want to tabulate results? (Y/N--default is N)",G$
10910 IF G$="N" THEN 11040
10920 G$="N"
10930 PRINTER IS 16                 ! Printout on screen
10940 INPUT "Do you want hard copy? (Y/N--default is N)",G$
10950 IF G$="N" THEN 10970
10960 PRINTER IS 0                  ! Hard copy from internal printer
10970 PRINT LIN(1);"LVL DEPTH, LVL TIME, AND TIME TO DATUM ALONG TRAVERSE"
10980 PRINT "Number   PN    LVL Depth   LVL Time    Time to Datum"
```

```
10990 IMAGE  X,3D,4X,3D,5X,3D.D,7X,3D.D,10X,3D.D
11000 FOR M=I1 TO I2
11010   PRINT USING 10990;M,2*M-1,Zw(M),Twx(M),Td(M)
11020 NEXT M
11030 PRINTER IS 16                 ! Printout on screen
11040 RETURN
11050 !
11060 Store_td:                     ! Sub: store time to datum and PN's
11070 G$="N"
11080 INPUT "Do you want to store time to datum? (Y/N--default is N)",G$
11090 IF G$="N" THEN 11440
11100 Q4=1                          ! Q4=1 is flag for first-time storage
11110 Name$=Na$&"TD"
11120 PRINT LIN(1);"Name of data storage file: ";Name$
11130 G$="N"
11140 INPUT "Has data storage file been used before? (Y/N--default is N)",G$
11150 IF G$="N" THEN 11170
11160 Q4=2                          ! Q4=2; flag to signal file PURGE needed
11170 Q3=1                          ! Q3=1; flag to store results on tape
11180 G$="Y"
11190 INPUT "Do you want to store results on tape? (Y/N--default is Y)",G$
11200 IF G$="N" THEN 11270
11210 BEEP
11220 PRINT LIN(1);"INSERT DATA STORAGE TAPE IN T15"
11230 GOSUB Ready                   ! Ready to proceed
11240 MASS STORAGE IS ":T15"
11250 DISP "STORING TIME TO DATUM DATA ON TAPE"
11260 GOTO 11330
11270 Q3=2                          ! Q3=2; flag to store results on disk
11280 G$="Y"
11290 INPUT "Do you want to store results on disk? (Y/N--default is Y)",G$
11300 IF G$="N" THEN 11440
11310 MASS STORAGE IS ":S7"
11320 DISP "STORING TIME TO DATUM DATA ON DISK"
11330 K=16*N0+150
11340 Nrec=INT(K/256)+INT(K/65536)+3
11350 IF Q4=1 THEN 11370            ! Branch if no PURGE required
11360 PURGE Name$                   ! Purging existing file name
11370 CREATE Name$,Nrec
11380 ASSIGN #1 TO Name$
11390 PRINT #1;Info$,Date_date$,Pnint,Ed
11400 FOR J=1 TO N0
11410   PRINT #1;Pn(J),Td(J)
11420 NEXT J
11430 IF Q3=1 THEN 11270            ! Branch to also store on disk
11440 RETURN
11450 !
11460 Comp_sc:                      ! Compute static corrections
11470 G$="N"
11480 INPUT "Do you want to compute static corrections? (Y/N--default is N)",G$
```

```
11490 IF G$="N" THEN 12440
11500 I7=(Sppn1(J4)+1)/2-Jp           ! Initiation for forward SP's
11510 I9=(Sppn2(J4)+1)/2-Jp           ! Initiation for reverse SP's
11520 FOR J=J4 TO J5                  ! FOR forward spreads
11530   I7=I7+Jp                      ! Forward SP's
11540   I8=I7+Os                      ! First detector on spread
11550   I9=I9+Jp                      ! Reverse SP's
11560   Tdsp1=Td(I7)                  ! Time to datum at forward SP
11570   Tdsp2=Td(I9)                  ! Time to datum at reverse SP
11580   I=I8-1                        ! Initiation for detectors, forward spd
11590   I4=I7-1                       ! Initiation for detectors, reverse spd
11600   FOR K=1 TO Nd                 ! FOR detectors
11610     I=I+1
11620     I4=I4+1
11630     Tscf(J,K)=-Tdsp1-Td(I)      ! Static correction for forward spread
11640     Tscr(J,K)=-Tdsp2-Td(I4)     ! Static correction for reverse spread
11650   NEXT K
11660 NEXT J
11670 G$="N"
11680 INPUT "Do you want to tabulate static corrections? (Y/N--default is N)",G$
11690 IF G$="N" THEN 12040
11700 PRINTER IS 16                   ! Printout on screen
11710 G$="N"
11720 INPUT "Do you want hard copy? (Y/N--default is N)",G$
11730 IF G$="N" THEN 11750
11740 PRINTER IS 0                    ! Hard copy produced
11750 IMAGE #,6(3D.D,4X)/
11760 PRINT LIN(1);"STATIC CORR FOR TRACES 1 THRU";Nd;"FOR FORWARD SPREADS"
11770 I7=(Sppn1(J4)+1)/2-Jp
11780 FOR J=J4 TO J5
11790   Seisf=Sppn1(J)+Osn            ! PN of first detector
11800   Seisl=Sppn2(J)                ! PN of last detector
11810   I7=I7+Jp
11820   I=I7+Osn/2
11830   PRINT "For record";J;" SP";Sppn1(J);"into spd from PN";Seisf;"to";Seisl
11840   FOR K=1 TO Nd STEP 6
11850     PRINT USING 11750;Tscf(J,K),Tscf(J,K+1),Tscf(J,K+2),Tscf(J,K+3),Tscf(J,K+4),Tscf(J,K+5)
11860     I=I+6
11870   NEXT K
11880 NEXT J
11890 PRINT LIN(1);"STATIC CORR FOR TRACES 1 THRU";Nd;"FOR REVERSE SPREADS"
11900 I7=(Sppn2(J4)+1)/2-Jp           ! Initiation of index
11910 I8=(Sppn1(J4)+1)/2-Jp
11920 FOR J=J4 TO J5                  ! FOR number of pairs
11930   Seisf=Sppn1(J)
11940   Seisl=Seisf+2*(Nd-1)
11950   I7=I7+Jp
11960   I8=I8+Jp
11970   I=I8
11980   PRINT "For record";J;" SP";Sppn2(J);"into spd from PN";Seisf;"to";Seisl
```

```
11990   FOR K=1 TO Nd STEP 6
12000     PRINT USING 11750;Tscr(J,K),Tscr(J,K+1),Tscr(J,K+2),Tscr(J,K+3),Tscr(J,K+4),Tscr(J,K+5)
12010     I=I+6
12020   NEXT K
12030 NEXT J
12040 G$="N"
12050 INPUT "Do you want to store static corrections? (Y/N--default is N)",G$
12060 IF G$="N" THEN 12440
12070 Q4=1                          ! Q4=1; flag for first-time storage
12080 Name$=Na$&"SC"
12090 PRINT LIN(1);"Name of data storage file: ";Name$
12100 G$="N"
12110 INPUT "Has data storage file been used before? (Y/N--default is N)",G$
12120 IF G$="N" THEN 12140
12130 Q4=2                          ! Q4=2; flag to signal file PURGE needed
12140 Q3=1                          ! Q3=1; flag to store results on tape
12150 G$="Y"
12160 INPUT "Do you want to store results on tape? (Y/N--default is Y)",G$
12170 IF G$="N" THEN 12240
12180 BEEP
12190 PRINT LIN(1);"INSERT DATA STORAGE TAPE IN T15"
12200 GOSUB Ready                   ! Ready to proceed
12210 MASS STORAGE IS ":T15"
12220 DISP "STORING STATIC CORRECTIONS ON TAPE"
12230 GOTO 12300
12240 Q3=2                          ! Q3=2; flag to store results on disk
12250 G$="Y"
12260 INPUT "Do you want to store results on disk? (Y/N--default is Y)",G$
12270 IF G$="N" THEN 12440
12280 MASS STORAGE IS ":S7"
12290 DISP "STORING STATIC CORRECTIONS ON DISK"
12300 K=N1*Nd*6+16*N1+150
12310 Nrec=INT(K/256)+INT(K/65536)+3
12320 IF Q4=1 THEN 12340            ! No PURGE required
12330 PURGE Name$                   ! Purging existing file name
12340 CREATE Name$,Nrec
12350 ASSIGN #1 TO Name$
12360 PRINT #1;Info$,Date_date$,Pnint,Osn
12370 FOR J=1 TO N1                 ! FOR number of record pairs
12380   PRINT #1;Sppn1(J),Sppn2(J)
12390   FOR K=1 TO Nd               ! FOR number of traces per record
12400     PRINT #1;Tscf(J,K),Tscr(J,K)
12410   NEXT K
12420 NEXT J
12430 IF Q3=1 THEN 12240            ! Branch to also store on disk
12440 RETURN
12450 !
12460 Elev_corr_fb:                 ! Sub: plot elevation-corrected arrivals
12470 G$="N"
12480 INPUT "Do you want to plot elev-corr arrivals? (Y/N--default is N)",G$
```

```
12490 IF G$="N" THEN 13450
12500 PRINTER IS 16
12510 Q2=2                          ! Q2=2; flag to plot elev-corr arrivals
12520 I7=(Sppn1(J4)+1)/2-Jp         ! Compute average SP to SP elevation
12530 I8=(Sppn2(J4)+1)/2-Jp
12540 Ns1=I8-I7+1
12550 FOR J=J4 TO J5                ! FOR number of pairs
12560   I7=I7+Jp
12570   I8=I8+Jp
12580   Es=Elev(I7)
12590   FOR I=I7+1 TO I8
12600     Es=Es+Elev(I)
12610   NEXT I
12620   Eavg(J)=Es/Ns1
12630 NEXT J
12640 I7=(Sppn1(J4)+1)/2-Jp         ! Comp elev corr for forward spreads
12650 FOR J=J4 TO J5
12660   A12=ASN(V1m(J)/V2m(J))      ! Critical angle within ABC interval
12670   C12=COS(A12)                ! Cosine of critical angle
12680   K1=C12/V1m(J)
12690   I7=I7+Jp
12700   Ecspf=-(Elev(I7)-Eavg(J))*K1     ! Elev correction at forward SP
12710   I=I7+Xcf(J)-1
12720   Vs=999
12730   Vb=-999
12740   FOR K=Xcf(J) TO Nd
12750     I=I+1
12760     Tp1(J,K)=Tf(J,K)+Ecspf-(Elev(I)-Eavg(J))*K1
12770     IF Tp1(J,K)<Vs THEN Mintf(J)=Tp1(J,K)
12780     Vs=Mintf(J)
12790     IF Tp1(J,K)>Vb THEN Maxtf(J)=Tp1(J,K)
12800     Vb=Maxtf(J)
12810   NEXT K
12820 NEXT J
12830 I7=(Sppn2(J4)+1)/2-Jp         ! Elev correction for reverse spreads
12840 I8=(Sppn1(J4)+1)/2-Jp
12850 FOR J=J4 TO J5
12860   A12=ASN(V1m(J)/V2m(J))      ! Critical angle within ABC interval
12870   C12=COS(A12)                ! Cosine of critical angle
12880   K1=C12/V1m(J)
12890   I7=I7+Jp
12900   Ecspr=-(Elev(I7)-Eavg(J))*K1 ! Elev correction at reverse SP
12910   I8=I8+Jp
12920   I=I8-1
12930   Vs=999
12940   Vb=-999
12950   FOR K=1 TO Xcr(J)
12960     I=I+1
12970     Tp2(J,K)=Tr(J,K)+Ecspr-(Elev(I)-Eavg(J))*K1
12980     IF Tp2(J,K)<Vs THEN Mintr(J)=Tp2(J,K)
```

```
12990      Vs=Mintr(J)
13000      IF Tp2(J,K)>Vb THEN Maxtr(J)=Tp2(J,K)
13010      Vb=Maxtr(J)
13020    NEXT K
13030 NEXT J
13040 G$="N"
13050 INPUT "Do you want to tabulate elev-corr FB's? (Y/N--default is N)",G$
13060 IF G$="N" THEN 13390
13070 PRINTER IS 16                 ! Display tabulation on screen
13080 G$="N"
13090 INPUT "Do you want hard copy of tabulation? (Y/N--default is N)",G$
13100 IF G$="N" THEN 13120
13110 PRINTER IS 0                  ! Produce hard copy of tabulation
13120 PRINT LIN(1);"ELEV CORRECTED FB TIMES FOR FORWARD SPREADS"
13130 I7=(Sppn1(J4)+1)/2-Jp         ! Initiate index for forward spreads
13140 IMAGE 2X,2D,4X,4D.D,9X,3D.D
13150 FOR J=J4 TO J5
13160    I7=I7+Jp
13170    I=I7+Xcf(J)-1
13180    PRINT "For record from SP";Sppn1(J);" at elev=";Elev(I7)
13190    PRINT "TRACE  ELEVATION  CORRECTED FB TIME"
13200    FOR K=Xcf(J) TO Nd
13210      I=I+1
13220      PRINT USING 13140;K,Elev(I),Tp1(J,K)
13230    NEXT K
13240 NEXT J
13250 PRINT LIN(1);"ELEV CORRECTED FB TIMES FOR REVERSE SPREADS"
13260 I7=(Sppn2(J4)+1)/2-Jp         ! Initiate indicies for reverse spreads
13270 I8=(Sppn1(J4)+1)/2-Jp
13280 FOR J=J4 TO J5
13290    I7=I7+Jp
13300    I8=I8+Jp
13310    I=I8-1
13320    PRINT "For record from SP";Sppn2(J);" at elev=";Elev(I7)
13330    PRINT "TRACE  ELEVATION  CORRECTED FB TIME"
13340    FOR K=1 TO Xcr(J)
13350      I=I+1
13360      PRINT USING 13140;K,Elev(I),Tp2(J,K)
13370    NEXT K
13380 NEXT J
13390 GOSUB Plot_fb_elev            ! Plot elev corrected first arrivals
13400 G$="N"
13410 INPUT "Do you want to compute apparent velocities? (Y/N--default is N)",G$
13420 IF G$="N" THEN 13440
13430 GOSUB Velocities              ! Comp app vel using elev-corr TB's
13440 Q2=1                          ! Q2=1; flag to return to no elev-corr
13450 RETURN
13460 !
```