Refraction Statics through Differential Receiver Delaytimes *

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Abstract

Frequent cycle changes within a shot record, cycle changes between consecutive shot records, and refractor changes within or between shot records all cause long as well as short period static errors at the surface consistent static decomposition stage. When first arrival pulses change character along a line and especially when refractors come to the surface, such cycle changes occur and are somewhat difficult to isolate. Such conditions can defocus the stack and have the potential to create misties because of large, long period static errors.

The method, which will be presented here, assumes that, due to such conditions, first arrival picks can not be taken to represent the depth changes of a single refractor. It also assumes that most time delays occur in the uppermost layer and consecutive receivers should exhibit the same delaytime differences no matter which refractor they are picked from.

When delaytime differences between consecutive receivers are smaller than cycle skips, reliable editing is possible for differential receiver delaytimes. Integration of differential delaytime profile gives the delaytime profile of the line. The DC component of the static solution is uncertain due to unknown cycles or refractor changes, yet it has no effect in focusing the stack.

The differential receiver delaytime technique has been checked with synthetics and successfully applied to real data. It offers an alternative to surface consistent decomposition techniques when the above mentioned problems exist and static changes between consecutive receivers are less than a first break cycle.

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*Paper presented at ASEG/SEG international Geophysical Conference and Exhibition, February, 1988, Adelaide, Australia

SUMMARY

Receiver delaytime differentiation provides a method to eliminate delaytime errors caused by cycle skips in the travel time picking and by refractor changes such as with outcrops. Basic assumptions of the method are that delaytime differences between consecutive receivers are smaller then cycle skips and are independent of which refractor the rays critically refract from provided that both rays in the pair belong to the same refractor. Delaytime differences are integrated to obtain the delaytime profile. The integration constant (bulk shift) is uncertain when many cycle skips or many refractors are present. Receiver delaytime profile loses its absolute meaning when delaytime differences for some receiver pairs can not be reliably determined due to recording conditions.

INTRODUCTION

The methods for continuous profiling for refraction work are approximately 50 years old at the time this paper is presented. Application of these techniques to the first breaks of production reflection data (i.e., refraction statics) is about eight years old. The last three years especially have shown great acceleration in refraction statics work. Therefore, considerable information is available in the literature concerning refraction statics and this paper will not go into detail on that subject. The method presented here was particularly designed to handle data with cycle skips and to extract weathering thickness information from one or many refractors.

The method can achieve its purpose except for noisy cases where fold is lost. In the remainder of this section an attempt will be made to tie the method to the rest of the related work on refraction statics.

The concept of differential statics is not a new one. Layat (1967) and Peraldi and Clement (1972) used differential statics to build up delaytime profiles for refraction data. However, they used differential shot delaytimes rather than differential receiver delaytimes. Recently, Musser et al. (1986) developed “Differential Statics” for travel times of reflection data. Their method uses differential statics for both receivers and shots and their times are two way travel times of reflection data. Hollingshead & Slater (1979), who are the pioneers of refraction statics, used differential receiver delaytimes in their equation, however, they did not explicitly derive differential receiver delaytimes because they rearrange their equations to sum before differentiation.

The GRM technique of Palmer (1981) which was derived for refraction profiles and has recently found application for refraction statics for reflection data, can be thought of as a surface consistent decomposition technique for refracted arrivals, except for the fact that shot statics are taken to be equal to receiver statics.

Farrel and Euwema (1985) correctly identified the problem as surface consistent decomposition of refracted ray paths. The same year Gulunay (1985) developed the Diminishing Residual Matrices (DRM) method for surface consistent decomposition of linearly moved out refracted arrival picks. Later the ABC method which originates for Heiland (1949) was computerized and presented as a surface consistent decomposition method which does not need refractor velocity (Gulunay, 1986).

In all of the above works, the programs developed assume that travel times used are free from mispicks or at least free from surface consistent mispicks. Although editing by the analyst is almost always useful, in some cases it may be too elaborate. Also, the data may not give clear information on which leg is being followed. Even if the analyst succeeds in being consistent within a shot, he may not even be on the same refractor between the beginning and the end of the line. Using more control for the “guide functions” of the first break picker is also possible but the basic purpose of this method is to find out if a machine with no interactive capabilities can do it correctly.

DELAY TIME DECOMPOSITIONS AND MISPICKS

Suppose numbers S_1, S_2,...,S_n represent shot delaytimes and R_1, R_2,••.,R_m represent receiver delaytimes. Then total delaytimes recorded would be

$$D_{ij}=R_i+S_j$$

which is shown in Table 1.

	S_1	S_2	...	S_N
R_1	$D_{11}= S_1 + R_1$	$D_{12}=S_2+ R_1$	...	$D_{1N}=S_N+ R_1$
R_2	$D_{21}= S_1 + R_2$	$D_{22}=S_2+ R_2$	...	$D_{2N}=S_N+ R_2$
...	..			
R_M	$D_{M1}= S_1 + R_M$	$D_{M2}=S_2+ R_M$	...	$D_{MN}=S_N+ R_M$

Table 1. Matrix structure of the total delaytimes.

The problem of decomposition is to find S_1, S_2, ..., S_n and R_1 ,R_2,...,R profiles from delaytime measurements Dij . As an example, if shot profile was (101,103,115,107,109) and receiver profile was (101, 102, 103, 104, 115, 106, 107, 108, 109, 110), the observed values would form as in Table 2.

	S1=101	S2	S3	S4	S5
R1=101	202	204	206	208	210
R2=102	203	205	207	209	211
R3=103	204	206	208	210	212
R4=104	205	207	209	211	213
R5=105	206	208	210	212	214
R6=106	207	209	211	213	215
R7=107	208	210	212	214	216
R8=108	209	211	213	215	217
R=109	210	212	214	216	218
R10=110	211	213	215	217	219

Table 2. A simple total delaytime matrix.

Decomposition techniques (e.g. the DRM technique Gulunay, 1985) solves for S_1 , ,...,S and R_1, R_2,...,R profiles accurately. However, if there were cycle skips on some picks, observations may look as shown in Table 3.

	S1=101	S2	S3	S4	S5
R1=101	242*	204	216	208	250*
R2=102	243*	205	217	209	251*
R3=103	244*	206	218	170*	252*
R4=104	245*	247*	219	171*	253*
R5=105	256*	258*	230	182*	264*
R6=106	207	249*	221	173*	255*
R7=107	208	250*	222	174*	256*
R8=108	209	211	213	215	257*
R=109	210	212	214	216	218
R10=110	211	213	215	217	219

Table 3. Same simple delaytime matrix except with cycle skips.

Here 40 msec was added (picks marked with *) to shots 1,2,5 and subtracted from shot 4 to illustrate cycle skips. When these picks are taken as true delaytimes, then the solutions of surface consistent decomposition techniques, including DRM, are totally erroneous.

On the other hand if one differentiates these numbers along each column, it is possible to avoid the mispicks. in the above example original data with no mispicks would give the differential values in Table 4.

	S1	S2	S3	S4	S5	Mean	integral
DR1	-	-	-	-	-	0	0
DR2	1	1	1	1	1	1	1
DR3	1	1	1	1	1	1	2
DR4	1	1	1	1	1	1	3
DR5	11	11	11	11	11	11	14
DR6	-9	-9	-9	-9	-9	-9	5
DR7	1	1	1	1	1	1	6
DR8	1	1	1	1	1	1	7
DR9	1	1	1	1	1	1	8

DR10	1	1	1	1	1	1	9

Table 4. Differential delaytime matrix of data with no cycle skips.

Integrated profile gives the correct receiver profile except a bulk value (101 msec) which can be calculated from

$$\frac{1}{2MN}\sum_{i=1}^{M}\sum_{j=1}^{N}D_{i,j}-\frac{1}{M}\sum_{i=1}^{M}R_i$$

Differentiation of mispicked data, similarly, gives the differential values in Table 5. If one flags out values which have absolute differentials above a certain threshold, then one would have the differential values in Table 6.

	S1	S2	S3	S4	S5		
DR1	-	-	-	-	-		
DR2	1	1	1	1	1		
DR3	1	1	1	-39*	1		
DR4	1	41*	1	1	1		
DR5	11	11	11	11	11		
DR6	-49*	-9	-9	-9	-9		
DR7	1	1	1	1	1		
DR8	1	-39*	1	39*	1		
DR9	1	1	1	1	-39*		
DR10	1	1	1	1	1		

Table 5. Differential delaytime matrix of data with cycle skips of 40 ms.

	S1	S2	S3	S4	S5	Mean	integral
DR1	-	-	-	-	-	0	0
DR2	1	1	1	1	1	1	1
DR3	1	1	1	-	1	1	2
DR4	1	-	1	1	1	1	3
DR5	11	11	11	11	11	11	14
DR6	-	-9	-9	-9	-9	-9	5
DR7	1	1	1	1	1	1	6
DR8	1	-	1	-	1	1	7
DR9	1	1	1	1	-	1	8
DR10	1	1	1	1	1	1	9

Table 6. Differential delaytime matrix after cycle skip editing.

Therefore, as long as the magnitude of the largest differential receiver delaytime is smaller than the cycle skip, it is possible to separate mispicks from actual delaytime variations and come up with the correct solution.

AVOIDING COMPLICATED MISPICKS

In the above example, cycle skips are assumed to be constant (40 msec) and differential receiver delaytimes are all consistent. However, for a given receiver, the differential values obtained from different shots may show distribution and clustering as in (18.2, 21.0, 3.2, 4.1, 3.3, 33.1, 34.1, 4.7, —10.3, —11.2, 23.1, 3.0). This means that a scheme for deciding what is correct is needed. The following describes how this is achieved.

Initially, these differentials are compared to a user given threshold value (for example, 20 msec per station). Absolute values which exceed this value are excluded from the analysis but the user is warned about their existence in case they might happen to be real differential delaytimes. Then, what is left are (18.2, 3.2, 4.1, 3.3, 4.7, —10.3, —11.2, 3.0) They are ordered to give (—11.2, —10.3, 3.0, 3.2, 3.3, 41., 4.7, 18.2> and these are put into bins of 3 msec wide as shown in Table 7. Then the bin which has the most population (1.8) is chosen. The mean of the values in the bin is determined.

Bin Center	-11.2	-8.2	-5.2	-2.2	1.8	4.8	7.8	10.8	13.8	16.8
Bın Population	2	0	0	0	3	1	0	0	0	1
Elements	-11.2 -10.3				3.0 3.2 3.3					18.2

Table 7. Most populated bin method for the choice of delaytimes

REFRACTOR VELOCITY

In the simple example given above, no attention was paid to travel time reduction (linear moveout) with refractor velocity and the derivation of such velocity. in this section I show that refractor velocity, needed for linear moveout with delay time methods, can be obtained from the differential receiver times. Note however that, in principle, the method presented does not need the refractor velocity.

As is well known, the front and back spread travel times show different behavior when the refractor has dip. However, the apparent difference between travel times of reverse shots provide information on delaytimes as well as refractor velocity profiles (Plus Minus method, Hagedoorn, (1958)). Putting in terms of the method presented here, differential travel times from negative and positive spreads contain velocity as well as delaytime information.

Let us illustrate this for a single refractor case: assuming shot delay equal to receiver delay, the travel time from shot j to receiver i is given by:

$$T_{i,j} = D_{i,j} + \frac{X_{i,j}}{V_{i,j}} \qquad (1)$$

where:

$$1 / V_{i,j} = \text{average } (1 / V_k)$$

for [min(i,j) < k <max(i,j)]   (2)

and

$$D_{i,j} = R_i + R_j$$

If the distance between receiver i and receiver i-1 is d_i then delaytime difference between two consecutive receiver stations on a common shot is given as

$$T_{i,j} - T_{i-1,j} = D_{i,j} - D_{i-1,j} - \frac{d_i}{V_i} \quad \text{when} \quad \mathrm{i} < \mathrm{j} \qquad (3)$$

and

$$T_{i,j} - T_{i-1,j} = D_{i,j} - D_{i-1,j} + \frac{d_i}{V_i} \quad \text{when} \quad \mathrm{i} < \mathrm{j} \qquad (4)$$

Averaging Eq.3 and 4 separately over all shots give:

$$t_i^p = r_i^p + \frac{d_i}{V_i} \qquad (5)$$

and

$$t_i^n = r_i^n - \frac{d_i}{V_i} \qquad (6)$$

where n and p stands for negative and positive spreads. That is, if N_i^p is the number of shots contributing to the sum at receiver station i and with positive offsets and if N_i^n is the number of shots contributing to the sum at receiver station i and with negative offsets then the quantities defined above, more precisely, are

$$t_i^p = \frac{1}{N_i^p} \sum_{j<i} (T_{i,j} - T_{i-1,j}) \qquad (7)$$

and

$$t_i^n = \frac{1}{N_i^n} \sum_{j>i} (T_{i,j} - T_{i-1,j}) \qquad (8)$$

and

$$r_i^p = \frac{1}{N_i^p}\sum_{j<i}(D_{i,j} - D_{i-1,j}) \qquad (9)$$

and

$$r_i^n = \frac{1}{N_i^n}\sum_{j>i}(D_{i,j} - D_{i-1,j}) \qquad (10)$$

Differential delaytime r_i between receiver i and i-1 is the average of differential receiver delay times from positive and negative spreads and is obtainable from differential traveltimes:

$$r_i = \frac{r_i^p + r_i^n}{2} = \frac{t_i^p + t_i^n}{2} \qquad (11)$$

As a side product the refractor velocity V_i below receiver i can also be obtained from differential travel times:

$$V_i = \frac{2d_i}{t_i^p - t_i^n} \qquad (12)$$

As seen from Eq.11, refractor velocity profile is not needed
In the calculation of differential delaytimes and its value can be calculated from the differential travel times t_i^p and t_i^n using Eq.12.

However, due to the size of the apparent slope on the travel times and due to possible uneven receiver station distances, auto editing of differential travel times t_i can be difficult to control and erroneous velocities as well as delaytimes may result. On the other hand, if a preliminary linear moveout is applied through a user given velocity profile, then differential travel times reduce in magnitude and become differential delaytimes. The error in the velocity profile can now be detected easily and corrected. The approach of using a preliminary velocity and then re—calculating the correct velocity was first done by Hirschleber (1971). However, the procedure presented in this paper differs from that and is explained below.

The user provides a preliminary correction velocity profile V_k^{prel} Then input picks are reduced with it using:

$$D_{i,j} = T_{i,j} - \frac{X_{i,j}}{V_{i,j}} \qquad (13)$$

and using inverse velocity sum for $V_{i,j}$ using V_k=V_k^{prel} in Eq 2.

Then differential receiver delaytimes r_i^p and r_i^n are obtained using Eq.9 and Eq.10. r_i^p and r_i^n values should generally agree with each other and their average can be taken as the difference in delaytime between receiver i and i -1:

$$r_i = \frac{r_i^p + r_i^n}{2} \qquad (14)$$

However, if preliminary correction velocity is in error one can deduce from Eq.5 and 6 that r_i^p and r_i^n estimates will differ from each other by $2E_i$ where

$$E_i = d_i\left(\frac{1}{V_i^c} - \frac{1}{V_i^{prel}}\right) \qquad (15)$$

and V_i^c is the correct refractor velocity. Therefore correction velocity could be obtained from the preliminary velocity and the delay time error, E_i , using

$$V_i^c = \frac{V_i^{prel}}{1 + \frac{V_i^{prel} E_i}{d_i}} \qquad (16)$$

This quantity is obtainable everywhere when there is fold on both positive and negative spreads (i.e. when both r_i^p and r_i^n are available). When fold on one of the sides is not present, interpolation and extrapolation is done on the velocity profile V_i^c. Then moveout with incorrect velocity V^{prel} is removed and a new moveout with the improved velocity V_i^c is done. Although this procedure does not alter the sum in Eq.14, moveout with accurate velocity matters at the line edges where fold is lost on one side. Updated values obtained with the correct velocity is integrated to obtain the delaytime profile:

$$R_i = \sum_{k=1}^{i} r_k \qquad (17)$$

The result is uncertain by a bulk which can be approximately obtained by assuming that half of mean value of the LMO'ed picks is equal to the mean value of the solution given by Eg.17. However, one should keep in mind that cycle skips make this assumption incorrect, therefore solution could be in error by some bulk amount.

Also, if certain r_k elements are incorrectly estimated, the integrated profile in Eq.17 could have cycle skips.

ELEVATION VS. REFRACTOR RELIEFS

All the above arguments apply as long as delaytime anomalies are caused by surface elevation relief and this process extracts delaytime anomalies caused by the surface, properly. However, refractor relief manifests itself at different receiver locations on different sides of the differential receiver profiles. For a given depth of refractor there is a distance, known as “migration distance” (Bartheimes, 1945; Pakiser and Black, 1956), by which these profiles shift from each other. This introduces some fluctuation to the differential receiver times picked for a given receiver pair and may make editing difficult in certain cases. This problem is not presently addressed by the method.

FIELD DATA EXAMPLE

Figure 1 shows the first break picks for two records from an overthrust line. Both records exhibit cycle skips which could have been eliminated to a certain degree with a more careful “guide function” in picking. However, it is not easy to decide which refractor one is following. Therefore, manipulation of a particular shot record is not easy or unique. Figure 3 also illustrates this fact. It shows two other shots at the end of the line. Note again that there is more than one refractor on these shots and one may wish to keep information from all of them.

Figures 2 and 4 show the same records after the application of delaytimes obtained by this method (plus 200 ms bulk shift downward). Figure 5 shows the receiver delaytime profile obtained and compares it to the elevation profile. Correlation between elevation and delaytime anomalies indicate that most of the delaytime anomalies in this line are caused by elevation changes. Also note the increase in delaytimes to the right hand side of the line. There is thickening in the overburden in that area. These figures illustrate the fact that short as well as medium period statics are resolved properly. Refractor changes are clearer now and one may wish to proceed with another iteration where proper guide functions for picking is easier to design.

CONCLUSIONS

Receiver delaytime differentiation is a useful tool for refraction statics when refractors change along the line or pick file contains cycle skips. The method combines delaytime method with reciprocal methods and yield accurate refractor velocity in single refractor case. The solution is independent of the refractor velocity except where fold is lost on one side such as line edges. The method which is successful when cycle skips are clear cut may fail and the solution drift when fold is lost on certain receiver pairs. Such cases need user intervention and is expected to be handled on work stations.

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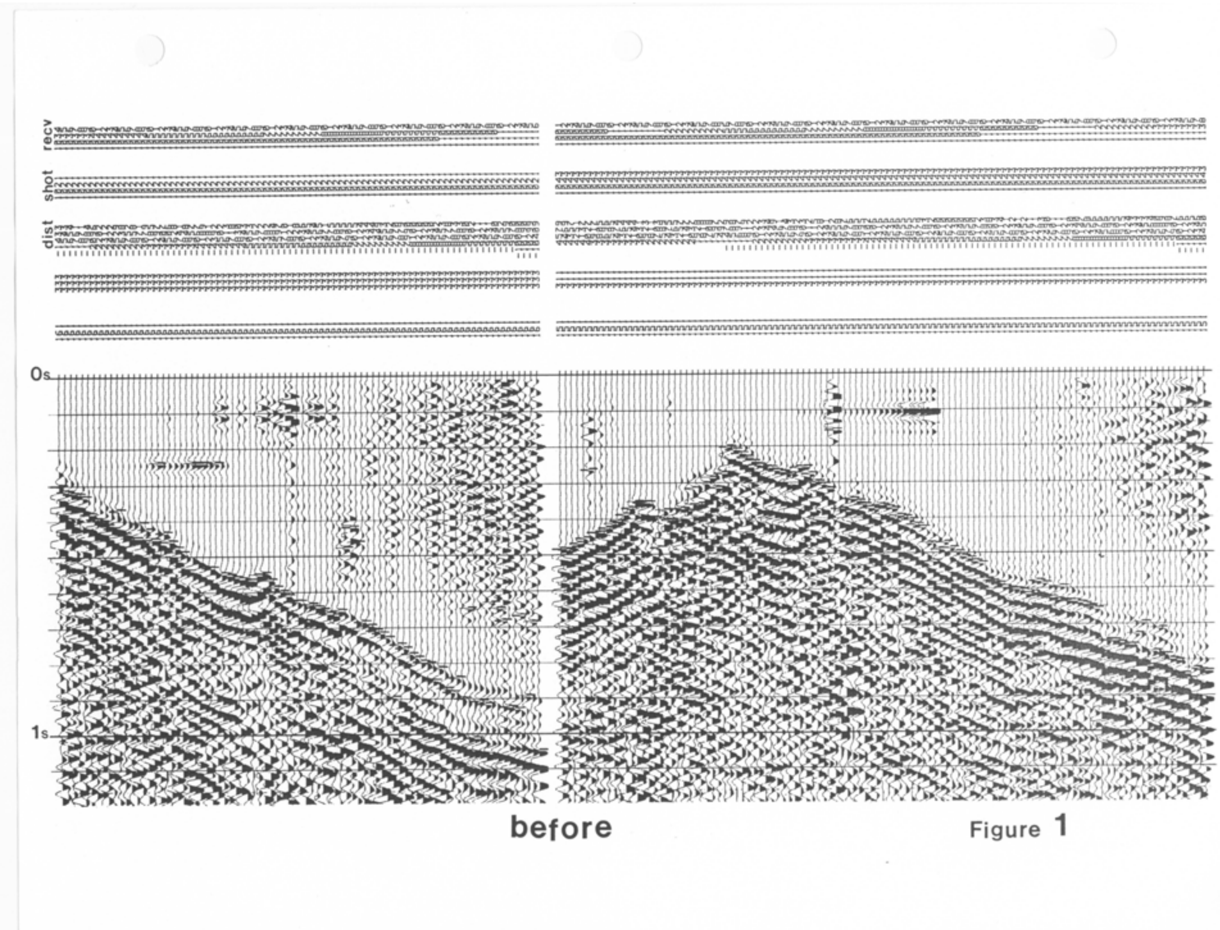

Fig. 1. Two records at the beginning of the line, before statics application.

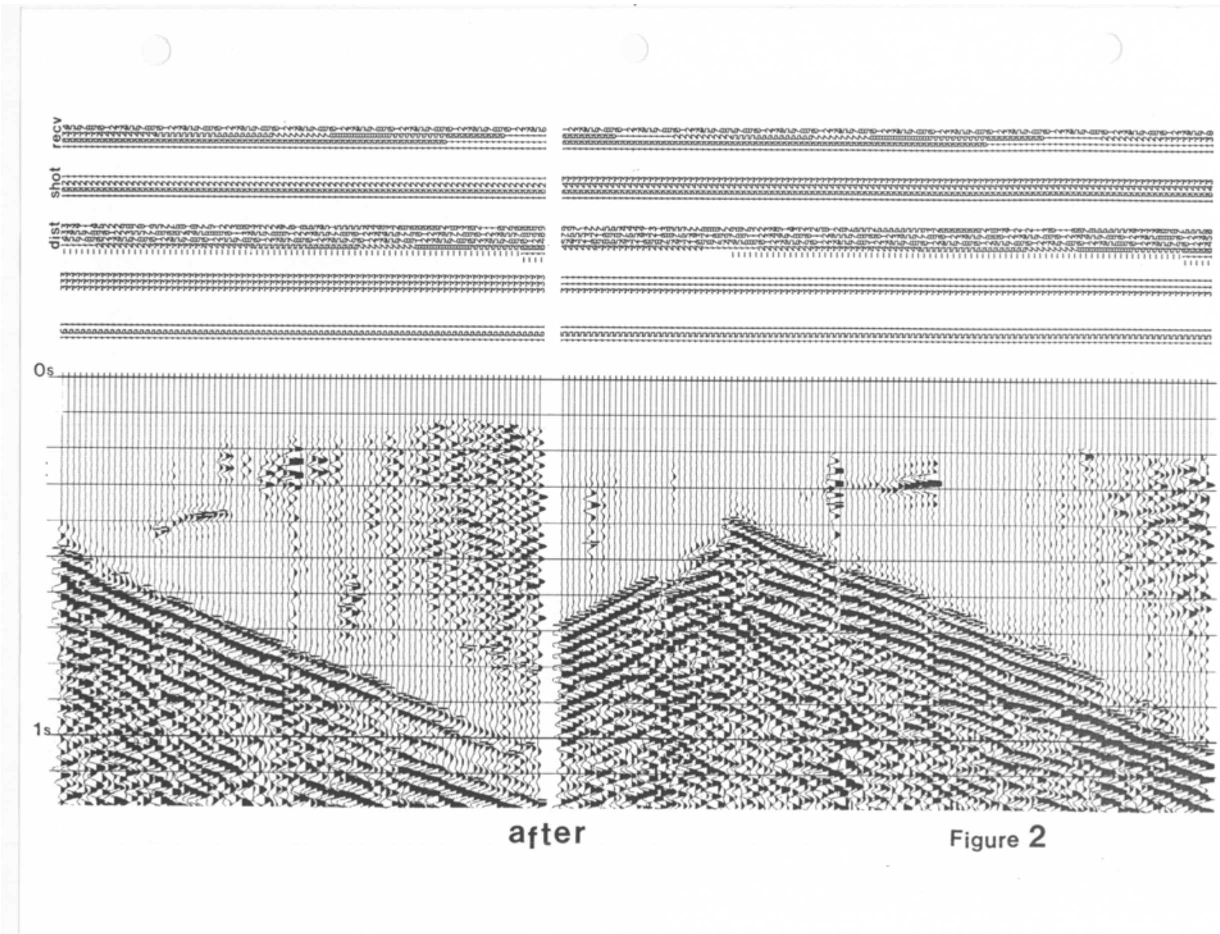

Fig. 2. Two records at the beginning of the line, after statics application.

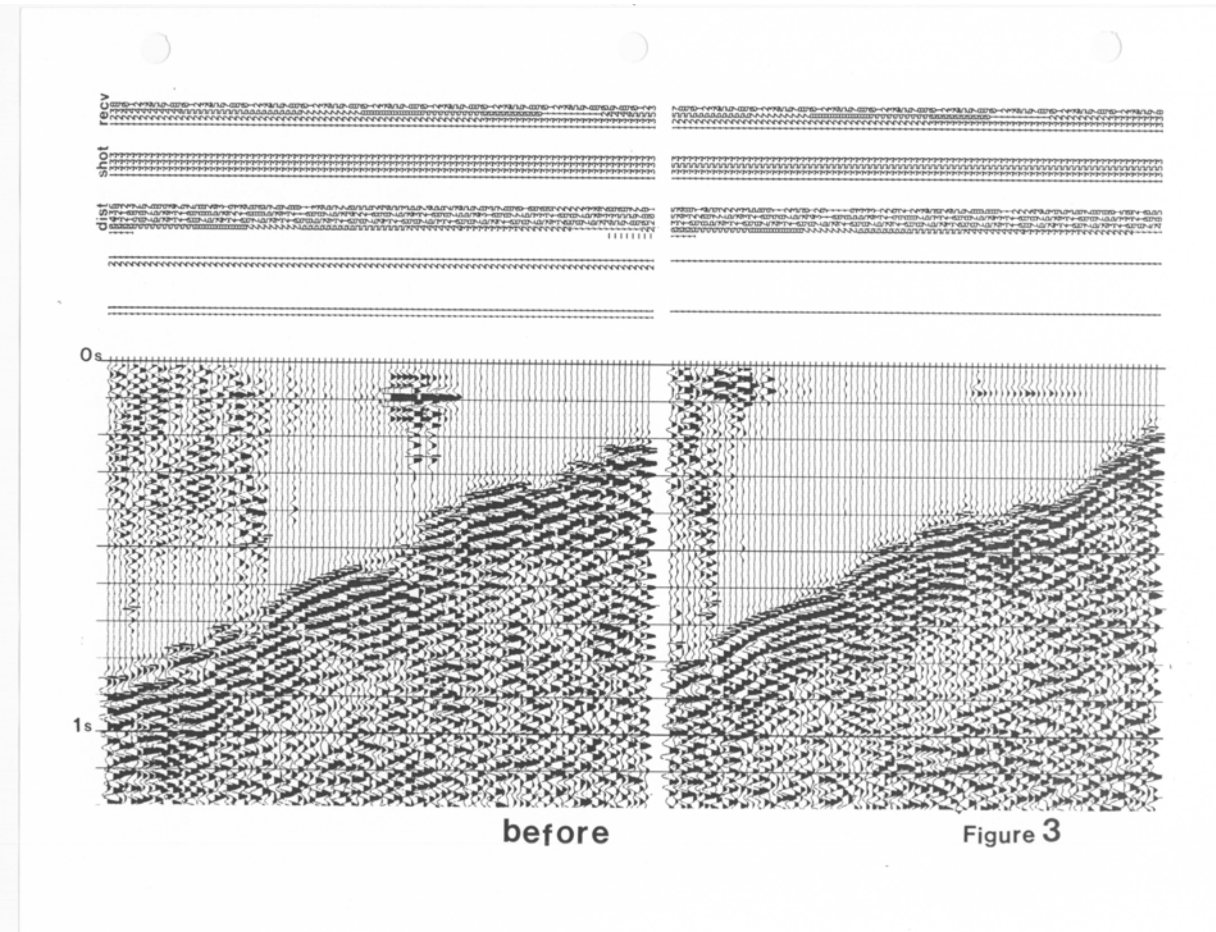

Fig. 3. Two records at the end of the line, before statics application.

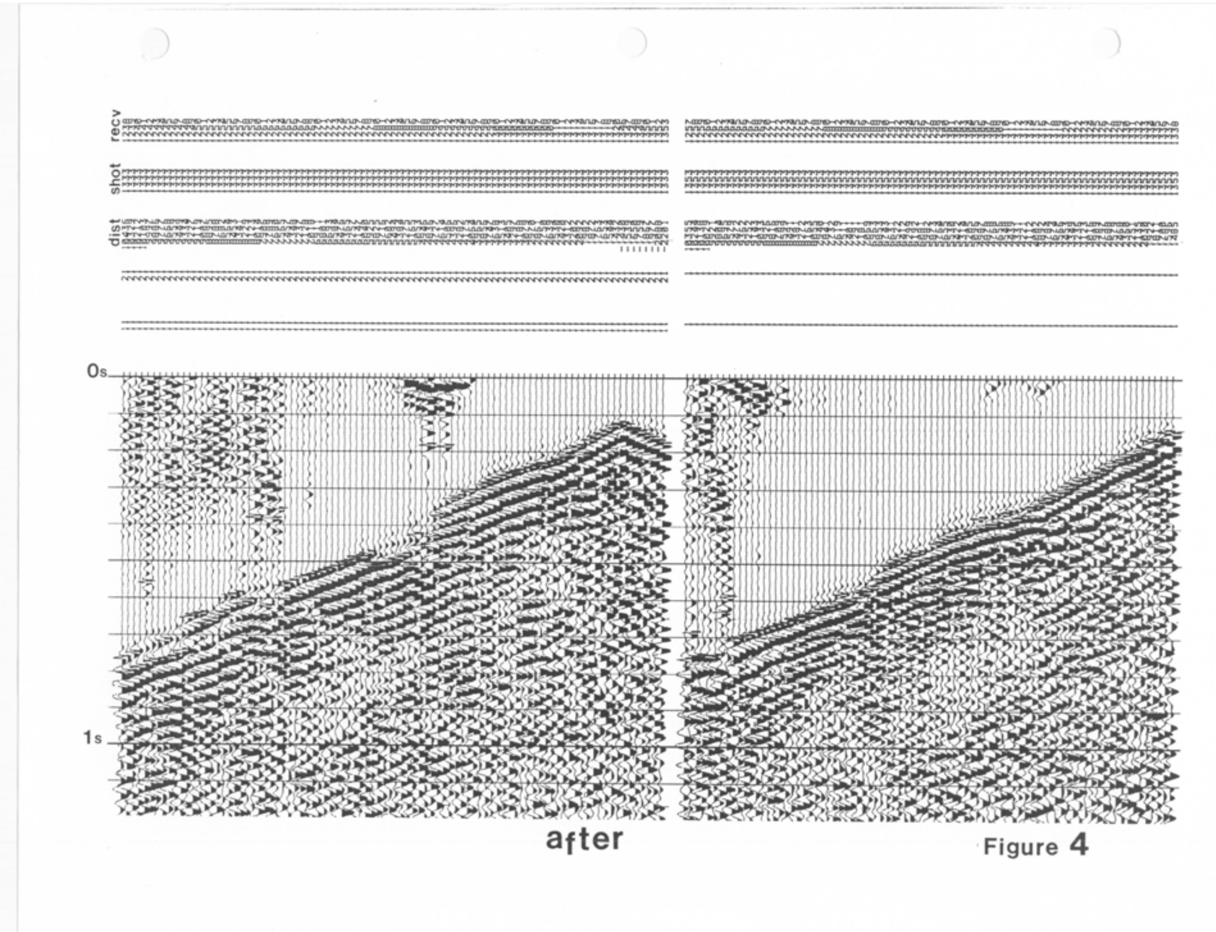

Fig 4. Two records at the end of the line, after statics application.

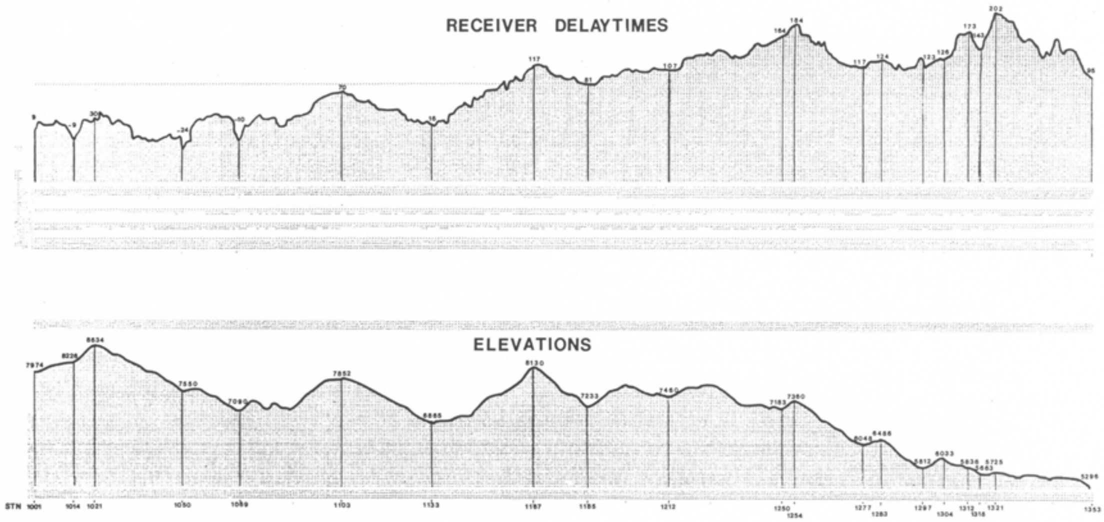

FIGURE 5

Fig. 5. Receiver Delaytimes obtained from data and comparison with the elevation profile.