SOME FACTORS AFFECTING THE PRECISION OF DELTA-T VELOCITY DETERMINATIONS

by

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ABSTRACT

Delta-T velocity measurements depend upon the determination of differences in reflection times between recordings at different distances from the source. There are numerous factors that limit the precision of such measurements. This paper examines the effects of some of these factors. In particular, the velocity errors caused by small errors in moveout estimates are related quantitatively to spread distance and two-way vertical time for areas of low velocity and areas of high velocity. The results of this study are presented for interval velocity determinations as well as for RMS and average velocities. The possible error due to anisotropy is also examined briefly.

Long recording spreads and digital processing have made the measurement of seismic velocities from reflection moveouts a practical and inexpensive by-product of the seismic survey. The geophysicist uses this velocity information for correlation, normal moveout correction, and depth computation. The geologist draws inferences about lithology from it and the petroleum engineer even uses it to predict formation pressures. It is therefore important to assess the reliability of this velocity information by analyzing, to the extent possible, the effects of variations in the factors which affect its precision.

Delta-T velocity measurements, as the name implies, depend upon the measurement of time differences. There are several different methods in current use for, in effect, measuring the moveout at different times along the time scale of the reflection records. There are numerous factors that limit the precision with which this can be done. These include spread geometry, reflector depth, static errors, signal to noise ratio, anisotropy and dipping reflectors among others. The scope of this report is limited to an analysis under the simplest possible assumptions of the effects of spread geometry, reflector depth, and anisotropy. As for dipping reflectors, we can minimize but not entirely eliminate the error from this source by confining our time comparisons to the differences that are observed between the traces of a common depth point. Moveout errors due to static errors may be reduced by increasing the number of common depth points used in the measurement. The degrading effect of noise may also be reduced by this averaging process and appropriate filtering.

Let us first try to analyze the effects due to ray path geometry. We will assume zero dip and propagation through media with isotropic velocities. Reflection time as a function of distance, vertical time, and RMS velocity is given to a very good approximation by the familiar expression of Fig. 1.

$$t^2 = t_o^2 + \frac{X^2}{V^2}$$

where t = two way reflection time
t_o = two way vertical time
X = distance from shot point
V = rms velocity

FIGURE 1

This is the equation of an hyperbola in t and x.

If t_1 and t_2 are the observed times of a reflection recorded at x_1 and x_2 then the expression of Fig. 2 follows.

$$V^2 = \frac{X_2^2 - X_1^2}{2\tau t_1 + \tau^2}$$

$$\tau = t_2 - t_1$$

FIGURE 2

The RMS velocity may thus be computed from the time and distance coordinates of any two points on the moveout curve.

We will now investigate the velocity errors that would be produced by introducing arbitrary errors into the value, tau, of the moveout. The velocities used were obtained from well surveys. RMS velocities were calculated from these surveys using the equations given by Dix (1955). The correct moveouts were calculated by solving the equation of Fig. 2 for tau using various values of t_1 and x_2. X_1 was held constant at 500 feet. In this way a matrix of the correct moveout values was constructed in which t_1 was kept constant in any given row and increased down each column and x_2 was kept constant in any given column and increased along each row. Fig. 3 illustrates such a matrix. This figure is for illustration only. Many more values were actually calculated.

	X_2 = 2000'	X_2 = 4000'	X_2 = 6000'
t_1 = 1 sec.	0.032	0.116	0.242
t_1 = 2 sec.	0.010	0.036	0.076
t_1 = 3 sec.	0.004	0.016	0.036

Moveout Matrix

(X_1 = 500')

FIGURE 3

Having thus determined the correct moveout that we would expect to see, we now introduce an arbitrary error of +2 ms into each moveout value in the matrix. Using these moveout values which have a known error, we can now calculate erroneous velocities which we can again organize in matrix form as illustrated in Fig. 4.

	Correct Velocity	$X_2 = 2000'$	$X_2 = 4000'$	$X_2 = 6000'$
$t_1 = 1$ sec.	6790	6629	6751	6773
$t_1 = 2$ sec.	7705	7259	7591	7654
$t_1 = 3$ sec.	8290	7505	8081	8196

Erroneous Velocities Caused by
2 ms Errors in Moveout Estimates

FIGURE 4

We now express the velocity errors as a percentage of the correct velocities and tabulate them as in Fig. 5.

	$X_2 = 2000'$	$X_2 = 4000'$	$X_2 = 6000'$
$t_1 = 1$ sec.	2.37%	0.57%	0.25%
$t_2 = 2$ sec.	5.79%	1.48%	0.66%
$t_3 = 3$ sec.	9.47%	2.52%	1.13%

Velocity Errors Caused by 2 ms.
Errors in Moveout Estimates

FIGURE 5

It is possible of course to compute interval velocities from the RMS velocities using the Dix (1955) equation. From these interval velocities one can compute average velocity. We find that percentage errors in calculated average velocities are almost identical with those of the RMS velocities so that these same percentage tabulations are good for average velocities. The preceding Figures are shown only for the purpose of illustrating the computational procedure.

The matrices actually calculated in this study were much larger than this one. Both time and distance were incremented at shorter intervals and carried to larger values. It is easy to see that such a tabulation can be contoured and Fig. 6 is such a contouring of percent velocity error corresponding to 2 ms of error in estimating the moveout. The ordinate is two way time and the abscissa is x_2 or maximum distance. This particular velocity from offshore Louisiana was quite low — average velocity only 8950 ft/sec. to a two way time of 4 sec.

To illustrate the use of Fig. 6, suppose the maximum distance is 4,000 feet, we see that the velocity error corresponding to a 2 ms moveout error increases from 1% at a time of 1.6 sec. to 2% at a time of 2.7 sec. and to 5% at a time of 5.0 sec. If the maximum distance is increased to 7,000 feet, the error is less than 1% down to 3.6 sec. and reaches 2% at 5.5 sec. Remember that we have introduced an error of 2 ms in the

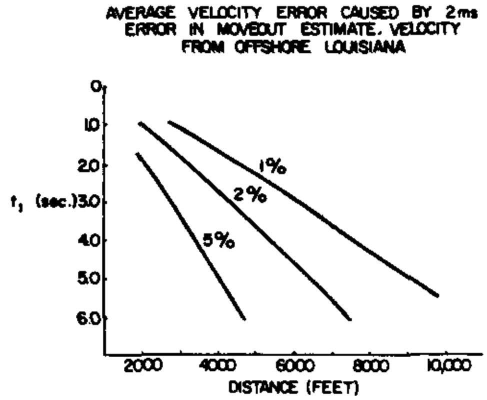

FIGURE 6

total moveout from 500 feet to the maximum distance. Since this is a low velocity and offshore where static errors are likely to be small, this probably represents a near optimum state of affairs.

What then do we find when we make such an analysis in a high velocity area? Fig. 7 is a similar graph of velocity error for a velocity from the deep Delaware Basin. The average velocity is between 13,000 and 15,000 ft./sec. down to 3 sec. two way time. In contrast to the previous low velocity case we see that now we have an error of 5% at a time of 2.2 sec. for a spread of 4,000 feet. At 7,000 feet distance we have 1% error at 1.2 sec. increasing to 2% at 2.7 sec.

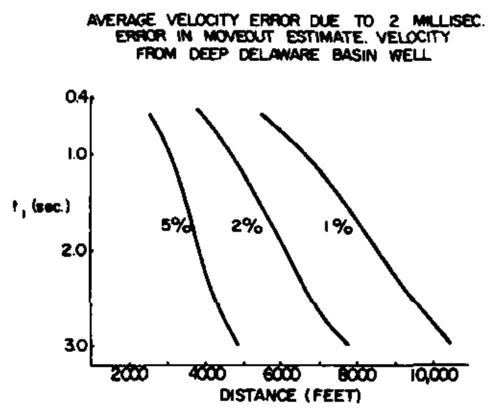

FIGURE 7

Obviously if we had plotted Fig. 6 and 7 with depths instead of times as ordinates they would have been quite similar.

We have seen then how the percentage velocity error decreases with increasing distance and how it increases with two way time. Also we have seen that for a given distance and time the error increases with the velocity. We may conclude that given reasonably long spreads and moveout estimates to within 2 ms we may expect average and RMS velocity calculations to be useable for the purposes enumerated at the beginning of this paper.

Let us now apply the same type of analysis to the calculation of interval velocities. To do this we have again arbitrarily introduced 2 ms errors into the calculated moveouts. This time, however, the errors are alternately positive and negative down each time column. We have again calculated the erroneous RMS velocities and from these erroneous interval velocities using the Dix equation. We have compared these with the correct interval velocities and expressed the difference as a percentage of the correct value.

Fig. 8 is computed from a typical Upper Texas Gulf Coast velocity using an interval of 100 ms down to 2 sec. two way time. As you can see the error increases rapidly with time. At a distance of 4,000 feet the error is greater than 10% below 1.0 sec. and at 7,000 feet is greater than 5% below 1.3 sec. increasing to 10% at 1.8 sec. If the interval is doubled to 200 ms the percentage errors become roughly half this large.

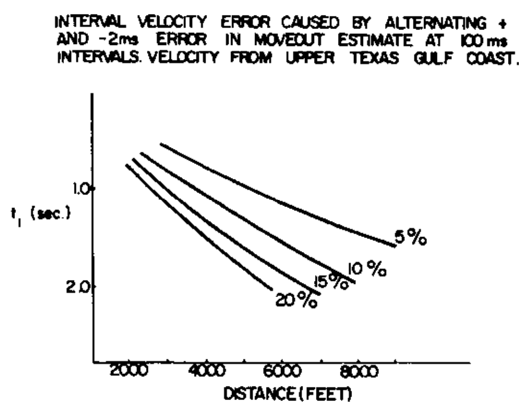

FIGURE 8

Returning now to the Deep Delaware Basin velocity (Fig. 9) we have made our calculations at 200 ms intervals to a time of 2.0 sec. It is clear that for spreads under 8,000 feet and times below one second we cannot afford to miss our moveout estimate by as much as 2 ms and hope to determine interval velocity with any certainty. Our recourse is to use a longer interval.

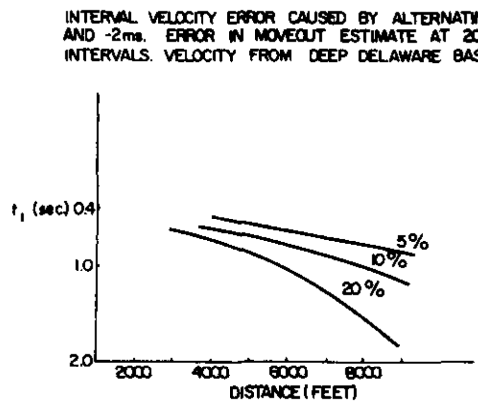

FIGURE 9

Fig. 10 shows the interval velocity error if an interval of 400 ms is used. On this graph the 10% error line is about where the 20% error line was for 200 ms intervals. By doubling the interval we have improved our precision by a factor of about 2. It still leaves a lot to be desired, however. For a spread of 7,000 feet we still have a 20% error in interval velocity at a time of 2 sec.

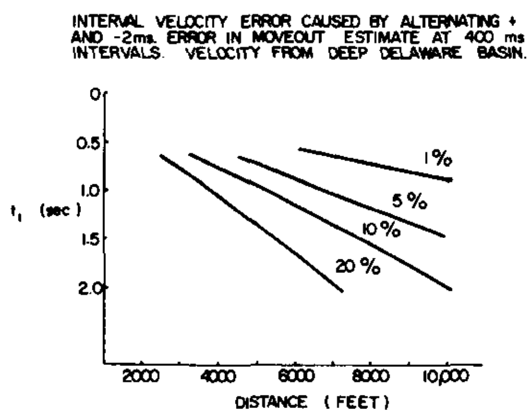

FIGURE 10

Fig. 11 concerns the 2 way time between 2 and 3 sec. for the deep Delaware Basin velocity. In this graph, percent error is plotted as ordinates and spread distance as abscissas. The curve on the right is the interval velocity error curve for a 500 ms interval centered at 2.5 sec. The curve on the left is for a 1 sec. interval centered at 2.5 sec. On the right the 10% error point falls at the 9,000 foot spread distance. We see that we do not gain a factor of 2 in precision in this case by doubling the interval. At 9,000 feet for example we have only reduced the error from 10% to 7%. At 6,000 feet we have reduced it from 22% to 14%. Considering that the interval from 2 to 3 seconds represents a thickness of some 7,000 feet of the section there is the question whether even a precise measurement of interval velocity would have much value as an average over such a thick interval.

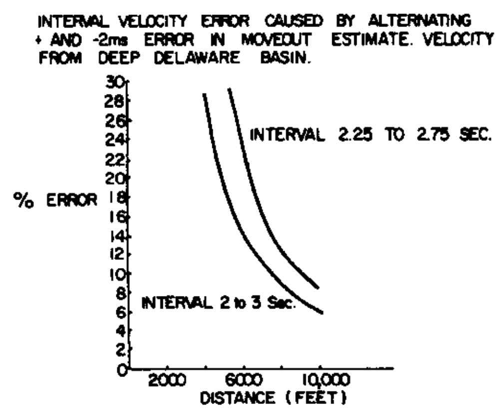

FIGURE 11

In the preceding illustrations we have seen the velocity errors introduced by errors of 2 ms in the moveout estimate. This 2 ms error value of course is purely arbitrary. It may or may not be representative of the error to be expected. Experience would tend to indicate that for data of excellent quality, moveout estimate errors may be in this range. As data quality deteriorates the errors probably become much larger.

Let us now turn our attention to the effect of anisotropy, again using the simplest possible assumption. Most of the well velocity information that we have to work with has been measured in a direction nearly normal to the bedding planes. Measurements parallel to the bedding planes have been made by a few workers and reported in the literature. Anisotropy factors have been reported to range from 1.0 to 1.4 for clastic sediments and from 1.08 to 1.3 for carbonates. Evaporites seem to range from 1.0 to 1.2. Postma (1955) has shown that thin interbedded layers, each of which is isotropic, can produce anisotropy on a larger scale, called transverse anisotropy. In any event it is reasonable to expect that some anisotropy is usually present and will result in our overestimating vertical velocity when measuring it with delta-t methods.

Uhrig and Van Melle (1955) have given the relation shown in Fig. 12.

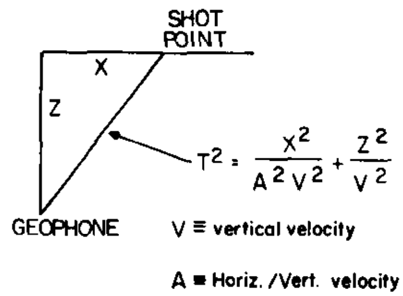

FIGURE 12

From this it is easy to show that the equation for the velocity along the diagonal ray path is given by the expression of Fig. 13.

$$V_s^2 = \left\{ \frac{A^2X^2 + A^2Z^2}{X^2 + A^2Z^2} \right\} V^2$$

$V_s \equiv$ velocity along slant ray

FIGURE 13

and the expression in parentheses is the square of the ratio of the diagonal velocity to the vertical velocity.

To get Fig. 14 we have used this relationship to calculate the difference between the diagonal velocity and the vertical velocity expressed as a percent of the vertical velocity. The ordinates are percent error and the abscissae are the ratios of spread distance to the reflector depth. A value of 1.2 was used for the anisotropy factor. We see that under this assumption the error is greater than 10% when the depth is less than .44 of the spread length. This improves to 2% when the depth is 1.3 times the spread length.

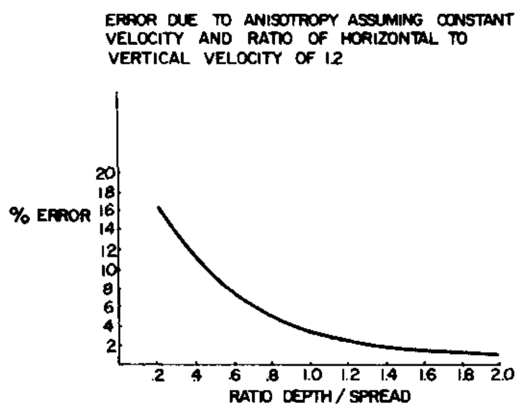

FIGURE 14

Fig. 15 shows the same information related to spread distance as abscissas versus two way vertical time as ordinates, where the depth-time conversion was made on the Upper Texas Gulf Coast velocity used in some of the earlier slides. For any given time and distance, these errors would be less if the vertical velocity were higher.

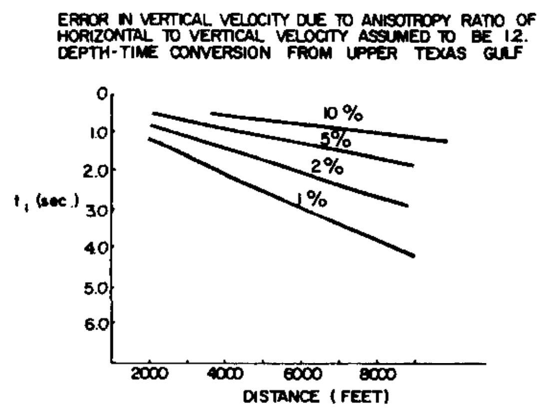

FIGURE 15

Although these calculations were based on the simplest possible assumption, that is straight line propagation, they are sufficient to show at least the order of magnitude of the errors to be expected.

Vander Stoep (1966) presented evidence that Gulf Coast sediments may have an anisotropy factor in the range 1.03. If this is the case the effect of anisotropy could safely be neglected in such an error.

Although errors in RMS velocity due to anistropy would have little adverse effect for stacking purposes, interval and average velocities calculated from these RMS velocities would of course generally tend to be in error on the high side.

In conclusion, we have seen that under favorable conditions of data quality and ray path geometry we may be reasonably confident that RMS and average velocities determined by delta-t methods are sufficiently accurate to be useful for purposes other than moveout correction for stacking. Interval velocities must, however, be interpreted with much more caution. Errors due to anisotropy are probably not severe under ordinary circumstances.

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