Preserving Far Offset Seismic Data Using Nonhyperbolic Moveout Correction

P. M. Gidlow and J. L. Fatti, Soekor (Pty) Ltd., South Africa*

SUMMARY

Two methods of estimating the fourth order term of the seismic travel time equation are described. These estimates are used in applying non-hyberbolic moveout correction to common mid point gathers. The first method consists of calculating the parameter C3 from stacking-velocity-derived interval velocities. The second method involves special C3 function analyses performed on CMP gather records.

Real data examples are used to illustrate the improvement gained by using non-hyperbolic moveout correction over conventional hyperbolic moveout correction. These improvements are shown both on CMP gathers and on the stack. Difficulties related to the application of the method are discussed and possible solutions suggested.

INTRODUCTION

For a horizontally layered earth the exact two-way travel time equation takes the form

$$T^2 = C_1 + C_2X^2 + C_3X^4 + \ldots \qquad \ldots\ldots\ldots (1)$$

(Taner and Koehler, 1969).

It has been the industry practice to approximate reflection moveout curves using only the first two terms of this equation (ie. hyperbolic moveout). This approximation is described by the equation

$$T^2 = T_0^2 + X^2/V^2 \qquad \ldots\ldots\ldots (2)$$

Where X is the source to receiver distance and V is the stacking velocity.

Velocity analyses are performed on CMP gather records to determine the stacking velocity function which is an approximation of the RMS velocity function (Al-Chalabi, 1974).

This hyperbolic approximation breaks down at larger angles of incidence (for offsets which are large relative to the reflector depth). At these offsets equation 2 is not accurate enough, and the result is that reflections curve upwards on the outer traces of the NMO corrected CDP gathers (figure 1). There are two solutions to this problem. One is to mute out the upwardly curving part of the events before stack. This is what is done in conventional data processing, and in the process valuable far offset reflection data are lost.

The other solution is to apply a more accurate approximation to the travel time equation (equation 1), as done by May and Straley, 1979.

There are instances when one wants to preserve those data on the CMP gather corresponding to larger angles of incidence. AVO analysis (see Smith and Gidlow, 1987) requires data from the widest range of offsets possible.

In this paper we discuss the estimation and application of the fourth order term (C3) of equation 1 in the fourth order moveout equation approximation

$$T^2 = T_0^2 + X^2/V^2(T) + C_3\,(T)\,X^4 \qquad \ldots\ldots\ldots (3)$$

using a simpler procedure than the iterative method of May and Straley (1979).

METHOD

The parameter C3 in equation 1 is a complicated function of interval velocity and two-way time (Taner and Koehler, 1969, p.879, equation A28) and its units are sec^2/m^4.

Since C3 is always negative, the fourth order approximation of the two-way travel time is always less than the hyperbolic approximation.

Equation 1 is a convergent series, so the fourth order approximation equation (3) is always a more accurate approximation to the travel time equation (1) than the hyperbolic moveout equation 2. The moveout correction defined by equation 3 will be referred to as NHM (Non Hyperbolic Moveout) correction.

Figure 2 shows four C3 functions computed from the interval velocity functions in figure 3. The different interval velocity functions correspond to models with increasing water depths. Each function has the same velocity at the sea floor, and each function has the same constant rate of velocity increase with depth. There is a large variation between the C3 functions at shallow times, but they all converge to approximately zero below a two way time of approximately 3.0 seconds; the shallow interval velocity values have a much larger effect on the C3 function than the deep interval velocities do.

Figure 4 illustrates the breakdown of the hyperbolic approximation at shallower depths, where incidence angles are largest. At larger offsets the two-way travel time is noticeably less than the hyperbolic approximation.

Two ways of estimating the C3 function used in the NHM correction will be discussed.

Firstly, since C3 is a function of interval velocity and two way time, it can be calculated from the interval velocities which are computed from stacking velocities derived from conventional velocity analysis. For the purposes of C3 analysis, the intervals defined by conventional velocity analysis are too thick, giving rise to discontinuous C3 functions. To rectify this, the time/stacking velocity curve is digitized at a fine sample interval (approximately 20 ms) and the interval velocity is determined for each interval. From this interval velocity function, a corresponding C3 function is computed.

The second method involves two stages. First, a conventional stacking velocity analysis is performed on the hyperbolic (low angle of incidence) portion of a CMP gather record. Next, the whole CMP gather record, including the large angle of incidence (non-hyperbolic) portion of the record, is displayed with NHM correction using a range of constant C3 values. The NHM correction for this display is done with one stacking velocity function, picked from the velocity analysis. This display is called a "C3 analysis", Figure 5. Events on this analysis are picked where the reflections are flat right out to the furthest offset.

A time-variant C3 function is then obtained by choosing those values of C3 corresponding to flattened events at different two-way times.

Figure 5 is an NHM-corrected CDP gather of synthetic traces which have been generated using equation 3. The NHM correction has been done with a single stacking velocity and a range of C3 values. The flattest event occurs at C3 value of -2.0×10^{-15} sec^2/m^4, which is the value that was used in generating the traces.

APPLICATION

The data used in this paper to illustrate NHM correction were acquired in the marine environment using a 4.5 km long streamer. It was with AVO analysis in mind that the longer streamer was chosen for the survey.

The stacking velocities were chosen in the usual way over offsets of the CMP gathers known to exhibit hyperbolic moveout. The high angle of incidence data were muted out for conventional velocity analysis. C3 analyses were then done at the velocity analysis locations along the line. A panel showing the C3 analysis of these data is shown in figure 6. The event whose minimum offset two-way time is approximately 1.0 second is flattest at a C3 value of about $-3.5*10^{-15}$ sec^2/m^4.

The additional amount of usable far offset information brought about by including the fourth order term of equation 1 is seen in figure 7.

This is a comparison between an NMO and NHM corrected CMP gather. The improvement in NHM over NMO correction is clearly seen on the event at 1.2 seconds. Figures 8 and 9 further exhibit the improvement of NHM over NMO correction.

C3 functions were then also calculated from the interval velocities derived from interpolated stacking velocity functions. The process of determining the C3 function by calculating it from interval velocities is a lot quicker and therefore cheaper than doing C3 analysis.

An important parameter to be chosen before the NHM corrected traces can be stacked, is the pre-stack mute. Data were stacked after NMO correction using a mute which excludes the non-hyperbolic portions of the events, and also NHM corrected and stacked using milder mutes.

DISCUSSION

Ideally, since the C3 parameter and stacking velocity are both functions of the same variable (interval velocity) they should be estimated simultaneously. May and Straley (1979) suggested a moveout correction technique based on the use of orthogonal polynomials for the determination of the fourth-order term in equation 1. One difference between their method and ours is that they use the whole CMP gather to determine the coefficients of both X^2 and X^4, whereas we mute out the non-hyperbolic portion of the gather before determining the coefficient of X^2 (ie. the conventional velocity analysis). This reduces the interaction between the coefficients of X^2 and X^4 in equation 3, and simplifies the procedure because it removes the need for the iteration required in the method of May and Straley.

The C3 analysis technique is preferable to computing the C3 function from stacking-velocity-derived interval velocities (the "computed C3 function" method) because it uses the data to estimate the C3 function which produces the best moveout correction. The computed C3 function method on the other hand assumes a particular earth model (horizontal isotropic layers), which does not necessarily fit the data as well. The main attraction of the computed C3 method is that it is easier to implement, because no C3 analyses are needed.

A problem yet to be addressed is that of the stretch produced by moveout correction. Where weighted stacking schemes are used to produce zero offset traces or traces that represent rock property, this move-out stretch poses less of a problem.

Another possible application of the technique is interval velocity estimation. Both stacking velocity and C3 are functions of interval velocity. One might be able to formulate the problem so that the only parameter which is to be estimated is interval velocity, rather than stacking velocity and C3.

CONCLUSIONS

We have shown how the fourth order term of the travel time equation can be estimated either by calculating it from interval velocities or by going through a process analogous to stacking velocity analysis. It has been shown that for larger angles of incidence, NHM correction is preferable to NMO.

Two problems with these methods are firstly, that C3 analyses are time consuming, and secondly, that calculation of C3 from stacking-velocity-derived interval velocities is subject to the inaccuracy of these interval velocities.

The success of the method is further limited by the introduction of low frequency data caused by moveout stretch. This study suggests that more work be done in an attempt to solve the stretch problem.

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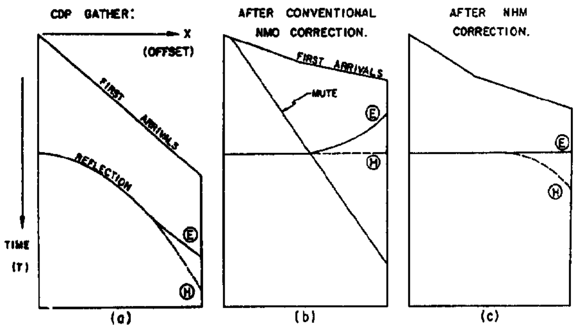

FIG. 1. Reflection event E curves upwards at far offsets after conventional NMO correction.

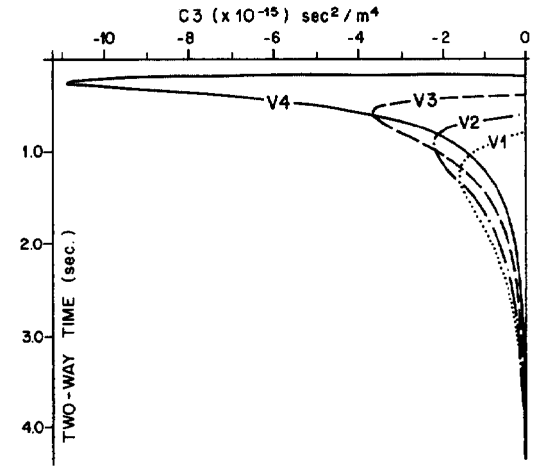

FIG. 2. Computed C3 functions.

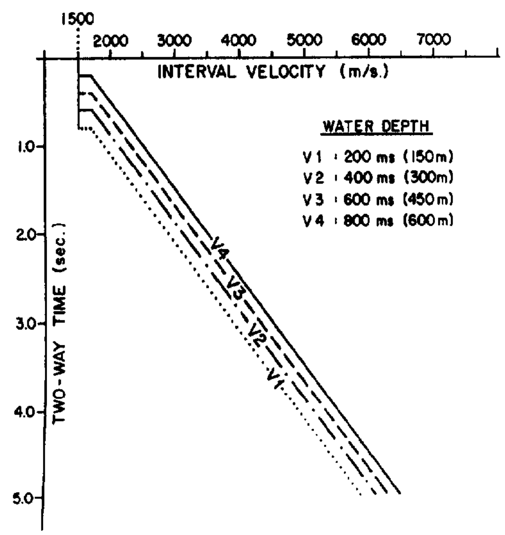

FIG. 3. Interval velocity functions from which C3 functions in figure 2 were computed.

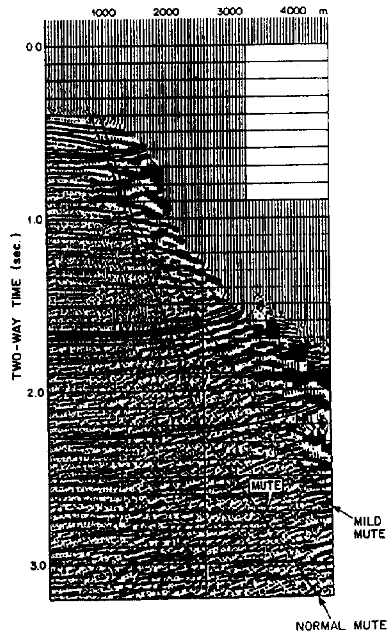

FIG. 4. CMP gather after NMO correction.

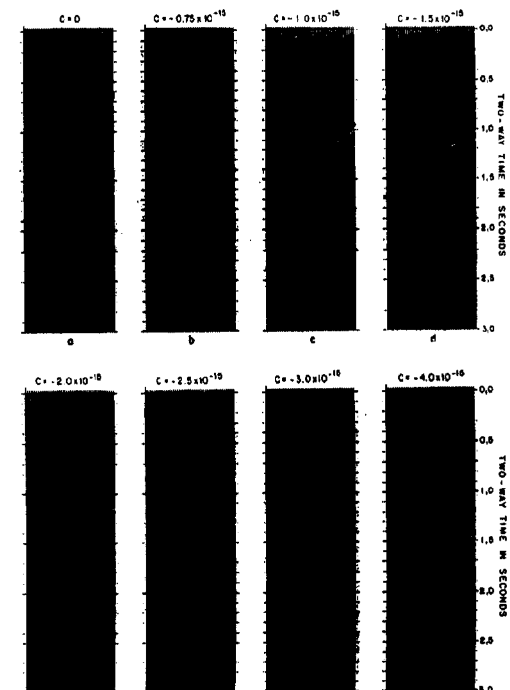

FIG. 5. C3 function analysis panel for CMP gather.

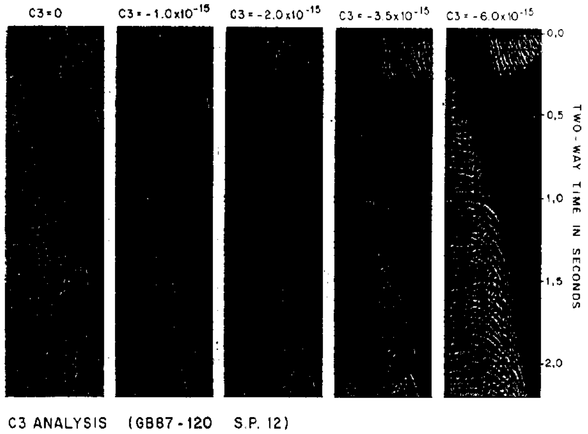

FIG. 6. C3 function analysis panel for CMP gather.

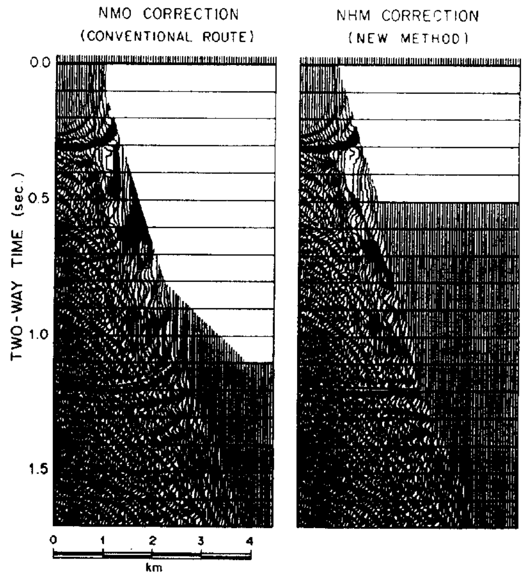

FIG. 7. Comparison between NMO and NHM correction.

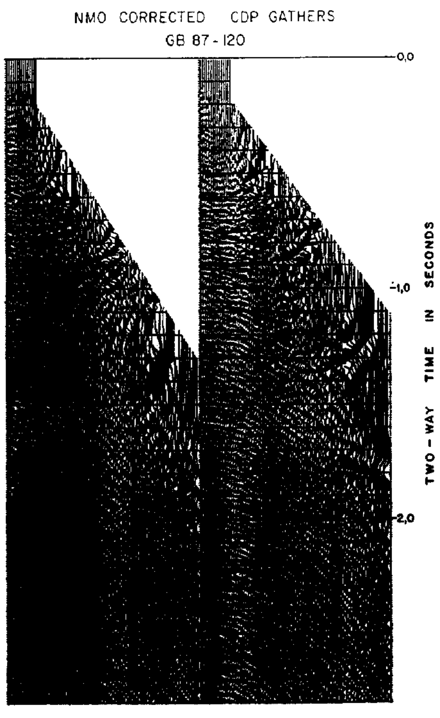

FIG. 8. NMO corrected CMP gather.

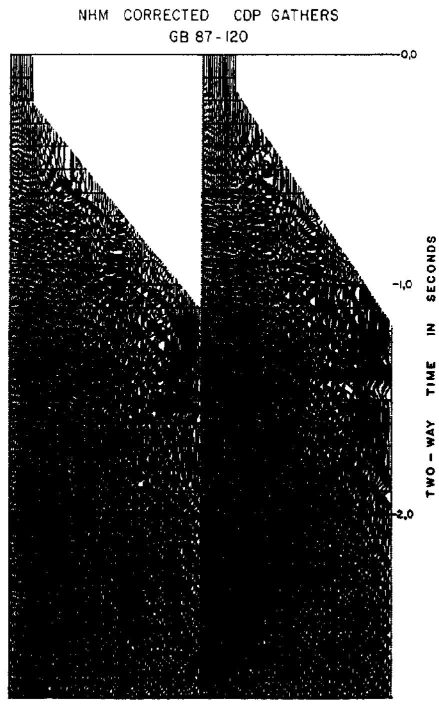

FIG. 9. NHM corrected CMP gather.