Modified Stacking Velocity Determination

SP 7.4

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SUMMARY

Stacking velocity analysis is important in seismic data processing. In this paper we propose a new and simple method to determine these velocities. First the data are mapped into binary data space using a cross-correlation technique. Than the stacking velocity and the corresponding two-way travel time are determined by means of a minimization process. The performance of the method is illustrated by a synthetic example and the resulting estimated velocities are in good agreement with the RMS velocities known in the literature.

INTRODUCTION

The method for stacking velocity estimation widely used and described (see, for example, Yilmaz, 1987) is based on measuring the coherency of the best hyperbolic fit, with the assumption that stacking velocities approximate Dix's RMS velocities. The present method estimates the modified stacking velocity on a binary data set by minimizing the difference between travel times and a family of hyperbolae defined by the zero-offset time and the stacking velocity. The travel times are obtained by mapping the original CMP data into a binary space using a cross-correlation technique. The basic equation has two degrees of freedom: not only are the velocities calculated, but also the zero-offset travel times. It turns out that the estimated stacking velocities are better approximated by the modified RMS velocities introduced by Fokkema and Van den Berg (1989) than by Dix's RMS velocities.

ARRIVAL TIME DETERMINATION

We determine seismic arrival times by mapping the CMP gathered data to the binary space. Let our original data in the CMP domain be given by D(r,t), where r is the offset and t is the travel time, and where

$$D(r,t) \in R.$$

Using a cross-correlation technique starting from the first trace we map our original recorded data into binary space $D^B(r,t)$, where:

$$D^B(r,t) \in \{0,1\}.$$

To obtain the binary data set, we first determine the timing of the events on the first trace in the data set. This is done by finding the local maximum, which is above a certain threshold, in a sliding window of the length equal to the wavelet duration. Second, we perform a cross-correlation of every trace in the CMP gather with the first, reference trace, in a window of the same length as the wavelet. We find the positions of the maximum cross-correlation in each sliding window for every pair of the traces starting at the positions of the seismic events found on the first trace. Because of the causality, the starting position of the window on the next trace slides down for the amount of the location of the maximum cross-correlation on the previous trace. The binary data set, consisting of spikes at the positions of the arrival times, is the input to the stacking velocity estimation.

STACKING VELOCITY ESTIMATION

The binary space can be thought of as a set of N families, where N is the number of layers:

$$D^B(r,t) = \{D_0[r,t_0(r)], D_1[r,t_1(r)], \ldots, D_N[r,t_N(r)]\}, \quad (1)$$

with the family property:

$$D_N\{(r,t_n(r)\} = 1, \text{ for } r_0 < r < R_n, \text{ and } n=0,1,2,\ldots,N, \quad (2)$$

where r_0 is the first offset, and R_n is the maximum offset corresponding to the family n.

In fact $t_n(r)$ furnishes the kinship in the family. In velocity analysis we are interested in a specific kinship, viz:

$$t_n^2(r) = T_n^2 + \frac{r^2}{V_n^2}, \quad (3)$$

where $T_n = t_n(0)$ is known as the normal two-way travel time (for $r=0$) and V_n is the so-called stacking velocity. The quantities T_n and V_n follow from the minimization of the expression:

$$\sum_{m=0}^{M(n)} \left| t_n^2(r_0 + m\Delta r) - \left[T_n^2 + \frac{1}{V_n^2}(r_0 + m\Delta r)^2 \right] \right|^2$$

leading to

$$T_n = \left(\frac{a_{22} b_1 - a_{12} b_2}{a_{11} a_{22} - a_{12}^2} \right)^{1/2} \tag{4}$$

and

$$V_n = \left(\frac{a_{11} b_2 - a_{12} b_1}{a_{11} a_{22} - a_{12}^2} \right)^{-1/2} \tag{5}$$

where Δr is the trace interval, and $M(n)$ is the maximum spatial sample number for the n-th family with offset

$$R_n = M(n)\Delta r + r_0. \tag{6}$$

The coefficients in equations (4) and (5) are given by:

$$a_{11} = \sum_{m=0}^{M(n)} = M(n) + 1, \tag{7}$$

$$a_{12} = \sum_{m=0}^{M(n)} (r_0 + m\Delta r)^2, \tag{8}$$

$$a_{22} = \sum_{m=0}^{M(n)} (r_0 + m\Delta r)^4, \tag{9}$$

$$b_1 = \sum_{m=0}^{M(n)} \left[t_n(r_0 + m\Delta r) \right]^2, \tag{10}$$

and

$$b_2 = \sum_{m=0}^{M(n)} (r_0 + m\Delta r)^2 \left[t_n(r_0 + m\Delta r) \right]^2. \tag{11}$$

The solution of the equations (4) and (5) for all layers found in the binary space data set leads to the zero-offset times and stacking velocities.

SYNTHETIC DATA EXAMPLE

The algorithm was tested on a synthetic data set consisting of primaries only, shown in Figure 1. The result of travel times determination is shown in Figure 2. Since the method obeys the causality, only the pre-critical times are detected and input to the velocity estimation algorithm. The velocity of the first layer was estimated with a relatively large error, mainly due to the large move-out of that layer. Figure 3 compares the velocities determined in three different ways: RMS velocities using Dix's formula, modified RMS velocities calculated analytically (Fokkema and Van den Berg, 1989), and the stacking velocities estimated with the present method. The agreement between the first two, calculated analytically from the model, and the velocity estimated from data, is very good.

We have also tested the algorithm performance in the presence of noise. The same model was used, with the source and the receiver ghost and multiples added. The weak reflectors, with the amplitude energy smaller than the energy of the strong multiples, were not detected. However, the velocity of the strong events was again estimated very accurately.

CONCLUSIONS

We have presented a new method for determining seismic arrival times and stacking velocities. It is a fast procedure, which estimates both zero-offset travel times and stacking velocities, with high accuracy for layers with a small move-out. The further improvements could be made by introducing an additional threshold value during the mapping procedure, which would probably help determining arrivals in the presence of strong multiples.

REFERENCES

Fokkema, J.T., and Van den Berg, P.M., 1989, Seismic inversion by a RMS Born approximation in the space-time domain: Geophysical Prospecting **37**, 53-72.

Yilmaz, O., 1987, Seismic data processing: Society of Exploration Geophysicists.

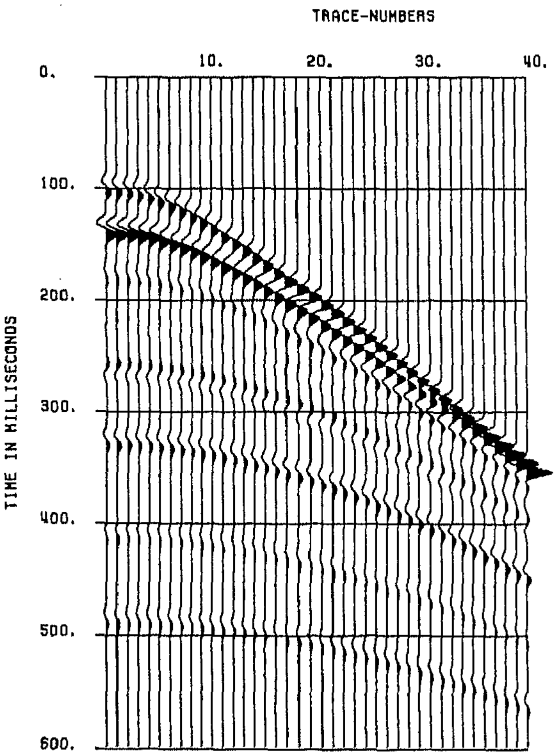

FIG. 1. Synthetic data set.

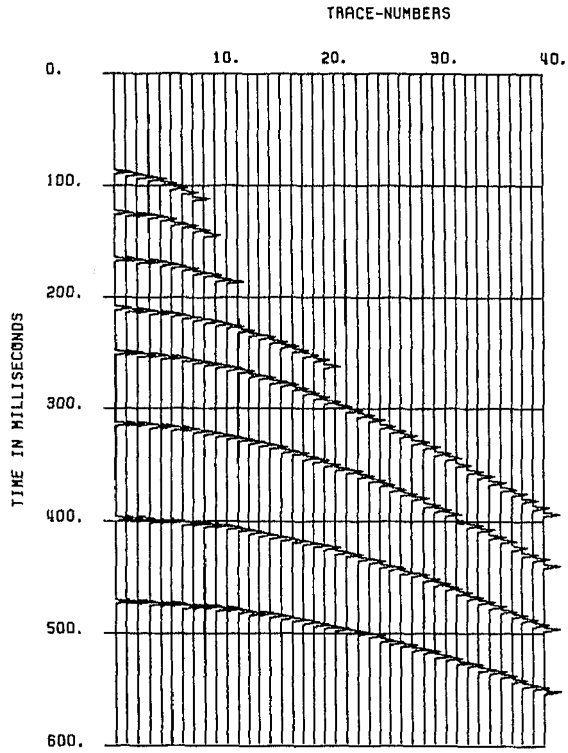

FIG. 2. Traveltimes estimated from synthetic data set.

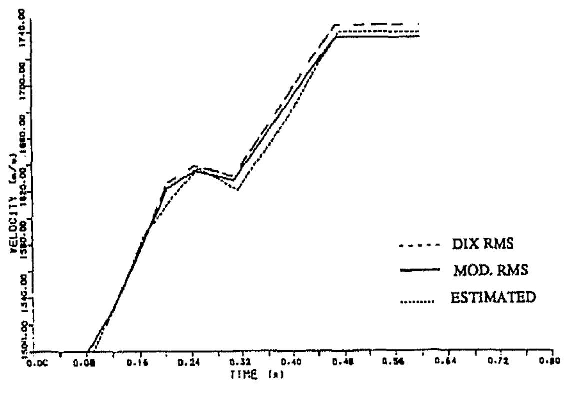

FIG. 3. Dix's rms velocities, modified rms velocities, and estimated stacking velocities from synthetic data set.