Estimating residual statics using prestack migration

John C. Bancroft*  Xinxiang Li
University of Calgary/CREWES, Canada  Sensor Geophysical Ltd
bancroft@geo.ucalgary.ca  xinli@sglnet.com

INTRODUCTION

Conventional estimation of residual statics
Elevation and velocity variations in the near surface cause different time shifts (the statics) to neighbouring traces that misalign reflection events. Elevation corrections to a datum provide an initial correction to the statics, with the remaining statics found by a process referred to as “residual statics analysis”. The realigned traces, when stacked, will improve the signal to noise ratio of the subsequent stacked sections.

An essential feature of this process is the defining of a model trace to which the neighbouring traces are compared. Conventional methods build model traces by stacking CMP gathers. These stacked traces may have additional filtering applied in the form of a spatially filtered brute stack. All traces in a CMP gather are then cross-correlated with their model trace. The cross-correlation provides a total static shift (residual static) that could be applied at this time, but it contains errors due to the alignment of noise and errors in the velocity that was used for the normal moveout (NMO) correction.

These residual static errors are minimised by decomposing the residual static into four components that are attributed to the appropriate source, receiver, offset, and geological structure. The offset component attempts to address the errors due to velocity model, while the structure term may be used to address errors between the model trace and the geology. The four components are estimated in the decomposition, but only the source and receiver components are applied to the input data. In areas that are difficult to process, the improved statics solution may aid in estimating an improved velocity model, which in turn will aid in estimating new residual statics. Several of these loops may be required to achieve a final estimate of the statics and velocities.

Each input trace requires NMO correction to be applied prior to forming the model trace. However, the NMO stretch produces a time-varying change in the actual static, which often requires the analysis to be performed at a number of narrow time bands across the section.

NEW METHOD

The new method builds model traces that are formed by using prestack equivalent offset migration (EOM). Bancroft et al. (1998). EOM is a process that divides prestack Kirchhoff migration into two parts; first, a gathering process that forms prestack migration gathers, and second, NMO correction and stacking of the gathers. (The NMO correction process is identical to the kinematics of zero offset migration). Only the gathering part of this process will be used in estimating the residual statics.

Prestack migration gathers
The prestack migration gathers are formed for every migrated trace and are similar in some ways to CMP gathers. All input traces that are within the migration aperture are sum or stacked into offset bins of each prestack migration gather. This is accomplished before any time shifting or NMO correction. The unique feature of EOM is that each input trace is placed at an equivalent offset that depends on the location of the migrated trace with respect to the location of the source and receiver. The inclusion of all input traces places the reflection energy for that specific migration location, on a hyperbolic path. These gathers may be processed with semblance analysis, (similar to CMP gathers) for accurate velocity analysis.

The computation of the equivalent offset $h_e$ is based on the energy from a scatterpoint that reduces the prestack double square-root (DSR) equation into a hyperbolic form. The geometry is illustrated in Figure 1. The surface location of a scatterpoint (SP) is also the location of the migrated trace and is chosen to be at $x = 0$. The midpoint location (MP) relative to the migrated trace is $x_s$, and the half source/receiver offset is $h$, giving the source and receiver locations as $S = x_c + h$, and $R = x_c - h$. Using an RMS velocity $V_{rms}(T_0)$ defined a scatterpoint at time $T_0$, the total travel time $T$ is the sum of the travel times of the source ray $t_s$ and receiver ray $t_r$. Using geometry and Pythagoras’s theorem, the prestack traveltime $T$ is found from the DSR equation

$$T(x, h) = \left[ \left( \frac{T_s}{2} \right)^2 + \frac{(x_s + h)^2}{V_{rms}} \right]^{\frac{1}{2}} + \left[ \left( \frac{T_r}{2} \right)^2 + \frac{(x_r - h)^2}{V_{rms}} \right]^{\frac{1}{2}}. \quad (1)$$

$T(x, h)$ describes a surface in the prestack volume $(x, h, t)$ that is commonly referred to as Cheops pyramid. The DSR equation (1) can be reduced exactly to the hyperbolic form

SUMMARY

A method is presented for estimating residual statics that are computed prior to normal moveout correction. No velocity information is required, and the offset and structure terms are eliminated from the decomposition.

Model source (shot) records are formed using the EOM method of prestack migration to provide a one-to-one trace for cross-correlation. After cross-correlation, the estimated time shifts are decomposed directly into source and receiver statics.

The method is stable for long time windows that are input to the cross-correlation, and provides solutions for structured data where other methods fail.
Residual statics using prestack migration

\[ T^2 = T_{ref}^2 + \frac{4(x^2 + h^2 - \frac{4x^2h^2}{T_{ref}^2v_{ref}^2})}{T_{ref}^2v_{ref}^2} \]  (2)

Defining the equivalent offset \( h_e \) to be

\[ h_e^2 = x_e^2 + h^2 - \frac{4x_e^2h^2}{T_{ref}^2v_{ref}^2} \]  (3)

Forcing the DSR equation into a hyperbolic form has the effect of co-locating the source and receiver at an offset \( h_e \) from the scatterpoint location as illustrated in Figure 1b. Note that the traveltime \( T = t_r + t_s \) in Figure 1a is equal to the same travel time \( T = 2t_e \) in Figure 2b.

The equivalent offset \( h_e \) matches the geometry of the actual source and receiver raypaths rather than the arbitrary source/receiver offset. Note that the equivalent offset is dependent on the location of the migrated trace (in this case located at \( x = 0 \)), and will vary for every migrated trace. Consequently, velocity analysis based on traces located at \( h_e \) will reflect actual errors in the velocity.

Since the formation of the prestack migration gathers is based on the energy reflected from a scatterpoint, they are referred to as common scatterpoint (CSP) gathers. An essential feature of these CSP gathers is that they are formed prior to any NMO correction.

All traces in the migration aperture are summed into offset bins of the CSP gather. The fold in each offset bin is very high and typically in the 100’s for 2-D data and in the 1000’s for 3-D data. Figure 2 contains two CMP gathers and one CSP gather. The first CMP gather in (a) contains traces located in order of offset, while the second CMP gather in (b) contains these same traces located at their actual offset \( h_e \). The CSP gather in (c), shows continuous coverage at all offsets, and even extends to offsets much greater than the maximum source receiver offset. This gather, not only contains the CMP traces of (b), but all the other input traces within the prestack migration aperture, as evident by the horizontal energy that comes from zero-offset reflections from horizontal data.

It is interesting to note that neighboring CSP gathers contain (virtually) the same input traces. It is the slight difference in the equivalent offset that focuses the energy for a specific location.

Typical EOM processing would proceed at this point to NMO correction and stacking all CSP gathers to create the traces in the prestack migrated section. This second step in EOM processing is not used in the residual statics process.

**Model traces**

The high fold in each offset bin of the CSP gather tends to average out any time shifts due to residual statics. A subsequent reversal of the gathering process distributes the energy in CSP gathers back to the original input trace locations throughout the prestack volume. The re-distribution of energy provides additional filtering of the residual statics. This forward and inverse gathered (FIG) prestack data may be sorted to source gathers and compared with the original source gathers. This comparison is visualized in Figure 3 where (a) is an original source record that has been pre-processed and (b) the FIG source record. Note in (b) the significant reduction in the general noise, and specifically the reduction in the time shift of the traces due to statics.

**Cross-correlation**

Each input trace now has its own model trace. Cross-correlation then proceeds as in the conventional method to find the trim static, and then with decomposition, the source and receiver static.

Since NMO correction has not been used in forming the model traces, there is no error term due to inaccurate velocities. Consequently there is no offset component required in the decomposition. Similarly, the structural term may also be eliminated as each trace has its own unique model trace. The trim statics is therefore decomposed directly to the source and receiver component. This is typically accomplished with a Gauss-Seidel numerical technique.

**DATA EXAMPLES**

Source and receiver statics were estimated and applied to data from a sedimentary basin and illustrated with one source record that is shown in Figure 3. The result of applying these corrections to the input data is illustrated in Figure 3c. Note...
in Figure 3 that the cross-correlation window can be very large and could span the entire trace.

A second data example is illustrated with the Marmousi data set. A stack of the input data is shown in Figure 4a. Random statics with a linear distribution of \( \sim 20 \, \text{ms} \) were assigned to each source and receiver and applied to all traces. These modified traces were then stacked to give the result shown in Figure 4b. The data was processed with a number of commercially available residual statics algorithms. All failed to converge to a solution except the method described in this paper. The algorithms failed because the structure was too complex, and the model traces were not stable over a window long enough to provide an adequate cross-correlation.

The results of estimating the residual statics, using model traces formed from the CSP gathers, is shown in the stacked section of Figure 4c. Note the significant increase in the resolution of the data and the large reduction in the noise. The remaining static errors have an amplitude mean that is close to 2 ms, however some still are as large as 5 ms at the edges of the data. It is emphasised that these residual statics were found independent of the velocity.

**COMMENTS**

Since there is no NMO correction in the original and model trace, the correlation window can be much larger, and the estimated static is applicable for the entire traveltime of the trace. It has been shown, though not included in this paper, that source/receiver statics that are estimated over different time windows yield the same static solution. The use of a large input time window to the cross-correlation will increase the signal to noise ratio (SNR) of the cross-correlation data, enabling a more accurate estimate of the residual static. This is particularly useful for the cases of noisy or structured data.

Using the CSP gathers to build the model traces does require more computational time. However time can be saved because the statics are estimated independent of the velocity, eliminating the need to iterate between solutions for the statics and velocities.

**CONCLUSIONS**

The estimation of residual statics can be improved by using model traces formed by forward and inverse gathering of CSP gathers. Each model trace is unique to each input trace, and is formed independent of velocity. Long time windows of trace data may be input to the cross-correlation because the process is performed prior to NMO correction.

**ACKNOWLEDGEMENTS**

The authors thank the sponsors of the CREWES project for their continued support.

**REFERENCES**

Figure 3. A source record showing a) the original data, b) the modelled data, and c) the corrected data.

Figure 4. Marmousi data example with a) the stacked section, b) the stacked section with synthetic statics, and c) the stacked section using the described residual statics algorithm.