Summary

Static correction is a major challenge for seismic exploration in mountains and desert terrains with loose stones or soil. Assuming an equivalent medium with quadratic velocity variation in depth (the quadratic velocity model, Figure 1), we present a traveltime inversion method to perform static correction in desert and loose terrains. The method includes fitting first break times using the quadratic velocity model, separating total intercept times into shot-point delay time and receiver-point delay time, and inversion for the near-surface quadratic velocity model. Processing of real data reveals the effectiveness of this method.

Quadratic velocity model and fitting of first break times

Desert terrains with loose soil (Figure 2) are characterized by significant lateral variations in thickness and lack of clear vertical layering. The first breaks in the seismic records from such terrains show a characteristics feature of bending events at near offsets and linear events at far offsets. With loose soil, pressure often varies continuously with depth, resulting in wave velocities varying continuously with depth. Turning waves (bending events) will thus arrive first at near offsets whilst refraction waves (linear events) of the bed rock will arrive first at far offsets (Figure 1). Therefore, we may use an equivalent medium with continuous velocity variation in depth to model desert terrains with loose soil.

A continuous velocity model may be described as a polynomial,

\[ V(Z) = \sum_{n=1}^{N} a_n Z^n. \]  

If \( N \) is large enough, equation (1) can be used to describe any type of continuous velocity structure. In practice, inversion is not stable with orders higher than two, so a quadratic curve is used instead,

\[ V(y, z) = V_d(y)(1 + \alpha z + \beta z^2), \]  

where \( y \) is the station coordinate. Equation (2) is referred to as the quadratic velocity model.

The bending first break times at near offsets may also be modeled by a quadratic curve. Since they are turning wave arrivals, the first break satisfies \( t = 0 \) at \( x = 0 \), where \( x \) is the source-receiver offset. Thus the first break time at near offsets may be written as,

\[ t = a_1^0 x + b_1^0 x^2, \]  

and the linear first break at offsets from refracted arrivals can be written as,

\[ t = t_0^2 + a_2^0 x, \]  

where \( t_0^2 \) is the intercept time and \( a_2^0 \) is the inverse of the bedrock velocity \( V_b \), as in the case of refracted statics correction. Assuming that the two curves intersect at offset \( x_0 \), we have,

\[ a_1^0 x_0 + b_1^0 x_0^2 = t_0^2 + a_2^0 x_0, \]  

which yields,

\[ t_0^2 = a_1^0 x_0 + b_1^0 x_0^2 - a_2^0 x_0. \]  

Note that at the intersection point, the straight line also represents the slope of the quadratic curve, so that, the first derivatives are equal. This yields,
\[
\begin{align*}
\left\{ 
\begin{array}{l}
a^{(i)} = a^{(i)}x + 2b^{(i)}x^2,
\end{array}
\right. \\
\left\{ 
\begin{array}{l}
b^{(i)} = -b^{(i)}x^2,
\end{array}
\right.
\end{align*}
\]

There are three independent coefficients: \(a^{(i)}, b^{(i)}\) and \(x_0\), which satisfy the following linear equation system,

\[
\begin{bmatrix}
x_1 & x_1^2 \\
x_2 & x_2^2 \\
M & M \\
x_{N+1} & 2x_0x_{N+1} - x_0^2 \\
M & M \\
x_M & 2x_0x_M - x_0^2 \\
\end{bmatrix}
\begin{bmatrix}
a^{(i)} \\
b^{(i)} \\
\end{bmatrix} =
\begin{bmatrix}
t_1 \\
t_2 \\
M \\
t_{N+1} \\
M \\
t_M \\
\end{bmatrix}.
\]

Equation (8) is solved using a least square method for a range of given \(x_0\). The \(x_0\) and the corresponding \((a^{(i)}, b^{(i)})\) that yield the minimum error of the least square objective function is the optimized solution.

Once \(a^{(i)}, b^{(i)}\) and \(x_0\) are determined, equation (7) can be used to determine \(t_0^{(2)}\) and \(t_a^{(2)}\). In this way, all coefficients of the quadratic curve and straight line are determined. Figure 3 shows an example of fitting first break times on shot point records from a real dataset.

**Separation of the intercept time \(t_0^{(2)}\)**

As in refraction statics (Chen 1990; Sheriff 1995), the intercept time \(t_0^{(2)}\) is the sum of shot point delay time (Ts) and receiver point delay time (Tr), which must be separated before inverting for the velocity model.

At first, the dichotomy method is used to divide the intercept times into two sets of delay times for source and receiver, respectively. A mean value is calculated for each set. According to the deviation of the sample from the mean value, the delay times are re-distributed to minimize the deviation. This process is repeated until the total mean square deviation is smaller than a given value, or the number of iterations exceeds a preset maximum. The final delay time sets are the result of the separation.

Figure 4 shows an example of separating the intercept time to delay times from real data.

**Inversion for the quadratic velocity model**

We have now determined the near offset travel times (equation 1), the delay times and the bed rock velocity (equation 2). Inversion of the quadratic velocity model is obtained by ray tracing, and the medium is discretized into small grid cells. There are three steps:

1) Define an initial velocity model \(V^{(1)}(y,z)\) from the near-offset travel times by turning-wave ray tracing.

2) Determine the thickness of the weathering layer or depth of the top interface of the bed rock \((z_0)\). This is achieved through refracted-wave ray tracing to match the delay time Ts or Tr using \(V^{(1)}(y,z)\) and \(V_b\) as input parameters. The top of the bed rock is usually a smooth surface. To meet this condition, Satisfy this constrain, \(V^{(1)}(y,z)\) and the delay time are usually smoothed prior to traveltime inversion. A subsequent smoothing of \(z_0\) may also be required.

3) Re-determine the coefficients \(\alpha\) and \(\beta\) in the velocity model \(V(y,z)\) as the final result. This is also achieved through refracted-wave ray tracing to match the original delay times using the smoothed \(z_0\), \(V_b\) and previous \(V_0(y)\) as inputs. This iteration is necessary to ensure that an optimum quadratic velocity model is obtained, which has a smooth bed rock interface but matches all the delay time as obtained from first break fitting.

**Calculation of the statics values**

Once the velocity model has been determined, we can calculate actual static values. For the \(j\)th station, use \(\epsilon_j\) and \(\epsilon_j'\) as the receiver and source statics, \(\tau_j\) and \(\tau_j'\) as the source and receiver delay time, \(e_j\) as the surface elevation, and \(d_j\) as the datum elevation.

For the receiver point, we have
where $z_0$ is the thickness of the weathering layer, $V_j(z)$ is the velocity of the weathering layer, and $V_{dj}$ is the replacement velocity at the $j$th station.

For the shot point, we have

$$t'_j = T'_j r_j z_j = \frac{z_j}{V_j(z)} V_{dj}.$$  
(10)

where

$$r_j = (\frac{z_0}{V_j(z)}) \frac{z_j - z_0}{V_{dj}}.$$  
(11)

**Examples**

Using the method described above, we have processed a range of seismic data acquired in desert terrains with loose soil in China. Some examples are shown in Figures 5 and 6. Figure 5 compares a shot record after applying different statics methods. Significant improvement has been achieved using the method presented in this paper. The first break arrivals are more continuous and reflection events can be identified (Figure 5b). The improvement is even more significant in the stacked section (Figure 6b).

**Conclusions**

We have presented a method for static correction in desert terrains with loose soil. There are two key elements in this method. The first is the use of an equivalent medium with quadratic velocity variation in depth to model the loose terrain in the near surface. The second is the separation of the first arrivals into turning wave arrivals at near offsets due to the loose terrain and refracted wave arrivals at the far offsets due to the bed rock. Applications to real data show significant improvements of subsurface imaging compared with other methods. This confirms that the method is particularly useful for static correction in desert terrains with loose soil.

**Acknowledgements**

We thank Changqing Oilfield of PetroChina for permission to show the data. This work is supported by the DTI/Trade Partners (UK) international collaboration programme and University of Petroleum through the Edinburgh Anisotropy Project (EAP) of the British Geological Survey, and is published with the approval of all project partners and the Executive Director of British Geological Survey (NERC).

**References**


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**Figure 1.** An equivalent medium with quadratic velocity variation in depth.
Figure 2. Examples of complex terrains.

Figure 3. Examples of fitting first arrival times.

Figure 4. Examples of separating intercept times to short and receiver delay times

Figure 5. Comparison of shot records with different methods for static corrections.

Figure 6. Comparison of stack sections with different methods for static corrections.