ASEG-PESA 2015
Geophysics and Geology together for Discovery
24th International Geophysical Conference and Exhibition
15–18 February 2015 Perth, Western Australia

Velocity analysis using zero-offset attributes in common source domain

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SUMMARY

Velocity analysis is one of the most critical stages in seismic data processing and the velocity errors influence the accuracy of the imaging. The conventional workflows, to obtain the migration velocity model, are generally labour intensive and time consuming. An experienced processor is needed to pick the velocities in the velocity spectrum. In this paper, we introduce another approach to obtain the velocity model using the first derivative of time with respect to offset (local slopes) in one domain, common source domain. In this time-effective approach, one order of differentiation has been reduced from the previous velocity analysis in common source domain, using zero-offset attributes. This velocity analysis and imaging are being done at the same time. There is no need to have any velocity model prior to imaging in this approach. The accuracy of the velocity analysis method is more robust than the previous technique because of the reduction in order of the derivatives needed. Computational experiments with synthetic seismic data examples confirm the theoretical expectations and demonstrate the feasibility of the proposed technique.

Key words: Velocity analysis, imaging, zero-offset, derivative, time-effective.

INTRODUCTION

In routine seismic imaging, the input migration velocity model should be provided by the seismic processor. In velocity independent imaging, it is possible to find the migration velocity and perform imaging simultaneously. This means it is not necessary to have the velocity model prior to imaging. The migration velocity can be extracted as a function of local derivatives of time with respect to the position of receivers.

According to Fomel (2011), the idea of utilizing the local derivatives from pre-stack data to calculate migration velocity goes back to Rieber (1936) and Riabinkin (1991). Ottolini (1983) derived the migration velocity for every point in the registered seismic data in order to apply it on his velocity- less migration algorithm for horizontal interfaces. Fomel (2007) extended and generalized this idea and designed another migration velocity pattern. This model is a function of local slopes in both common-offset and common-midpoint domains. Cooke et al. (2009) proposed another velocity analysis technique so that it was in terms of horizontal slopes in both common offset and common receiver domains. The problem of the last two models is that the information in two different domains is not always available and they need interpolations to fill the empty traces. To address this issue, Bóna (2011) designed another velocity pattern, to migrate planer reflectors, in terms of local derivatives in just one domain, common source domain. This model was a function of the relevant apparent slowness and curvature.

In this abstract, we continued the work that had been done by Bona (2011). We simplified the velocity equation by removing one order of differentiation from his velocity formula. In order to do that, zero-offset attributes, containing vertical travel time (t_0) and apparent slope (p_{x0}), have been used. We use plane wave destructive filter (Fomel, 2002, Milano et al. 2011), numerical differentiation (Bona, 2011).

METHOD

The velocity model obtained by Bóna (2011) is

$$p^2 = p_x{}^2 + tp_{xx}\,. \tag{1}$$

Where t, p, p_x and p_{xx} are two-way-travel time (TWT), effective slowness, local slope and the apparent curvature in a typical shot record, respectively (Figure 1). Using the zero-offset attributes, vertical TWT (t_0) and the local slowness at the position of seismic source (p_{x0}), there is no need to calculate the local curvature, which is the second derivative of time with respect to offset.

The cosine ratio of the effective dip angle (θ) at the location of the seismic source (s) and at the position of the seismic image source (s') can be expressed as follow;

$$cos(\theta) = -\frac{p_{x0}}{p} \tag{2-a}$$

$$cos(\theta) = \frac{x_{s'}}{vt_0} = p\frac{x_{s'}}{t_0} \tag{2-b}$$

Based on Figure 1, the ray path from the source to the reflection point and from reflection point to the position of the receiver ($\overrightarrow{sor}$) is equal to the ray path from the image source to the receiver ($\overrightarrow{s'or}$) and is equal to $vt = \frac{t}{p}$. Regarding to the corresponding cosine ratio for the effective reflection angle (α)

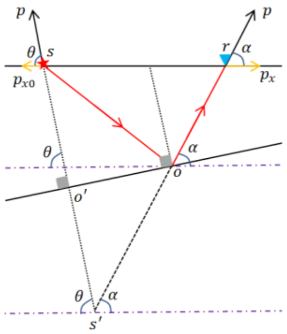

Figure 1.Reflection ray geometry in effective homogeneous medium from a dipping reflector

at the location of the seismic receiver ($\cos\alpha = \frac{p_x}{p}$) and writing the distance between the source and the receiver ($sr = h$) in terms of the ratio, leads to the corresponding x coordinate of the image source.

$$h = x_{s'} + \frac{t}{p}\cos\alpha \tag{3-a}$$

$$x_{s'} = h - \frac{tp_x}{p^2} \tag{3-b}$$

Equating (2-a) and (2-b) and substituting $x_{s'}$ from (3-b) gives the velocity function.

$$p^2 = \frac{tp_x - p_{x0}t_0}{h} \tag{4}$$

The above velocity function does not suffer from the numerical errors caused by the local curvature calculation. We used the above velocity formula and Equation (1) derived by Bóna (2011) to migrate data in common source domain.

APPLICATION TO SYNTHETIC DATA

Figure 2 shows a synthetic model and the relevant zero-offset section. Acquisition parameters used to generate the synthetic data are listed in Table 1. Migration results obtained from the velocity Equations 1 and 4 are shown in Figure 3. In this example, we used plane wave destructive filter and numerical differentiation to calculate the local slopes and the apparent curvatures, respectively.

a) b)

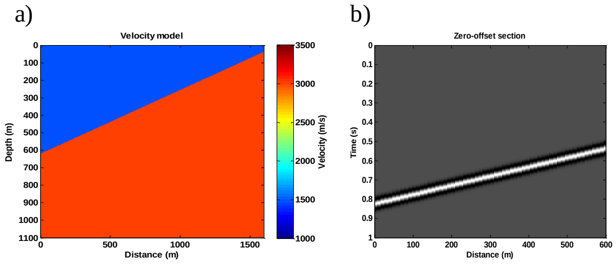

Figure 2. a) Velocity model used to generate synthetic data. Compressional velocities from top to bottom are 1500 and 3000 (m/s). b) Zero offset section obtained from the contribution of 60 shot records.

Maximum depth (m)	1000
Maximum distance (m)	1600
Sampling interval (ms)	2
Geophone spacing (m)	10
Number of receives per shot	100
Number of shot records	60
Maximum time in each record (s)	1
Ricker Wavelet- Dom. Freq. (Hz)	15
Acquisition type	Off-end
Dip (degree)	20

Table 1. Acquisition parameters used to generate synthetic data by acoustic modelling.

The seismic events are migrated in each shot record and migrated shot gathers (60 gathers) are stacked to obtain the final image and stack section. Based on the migration result obtained from Equation 1 shown in Figure 3a, the seismic energy is distributed in the whole migration space whereas the use of Equation 4 shows the seismic energy is aligned with the appropriate position of the dipping interface (Figure 3b). The reason for the resolution improvement is the reduction of numerical errors caused by the calculation of second derivatives.

We derived and used the following migration equations obtained from double square root function (DSR) (Claerbout, 1985). It is worth noting that use of the migration equations derived by Bóna (2011), leads to the same results.

$$x_o = \frac{1}{2}\frac{-t^2 + \frac{2tp^2h}{p_x} - p^2h^2}{p^2\left(\frac{t}{p_x} - h\right)} \tag{5}$$

$$t_0 = \left(-\frac{-t^2 + \frac{2tp^2h}{p_x} - p^2h^2}{p^2\left(\frac{t}{p_x} - h\right)} + 2ph\right)\sqrt{\left(\frac{p}{p_x}\right)^2 - 1} \tag{6}$$

Figure 4a shows the relevant zero-offset section for the synthetic seismic operation.

a) b)

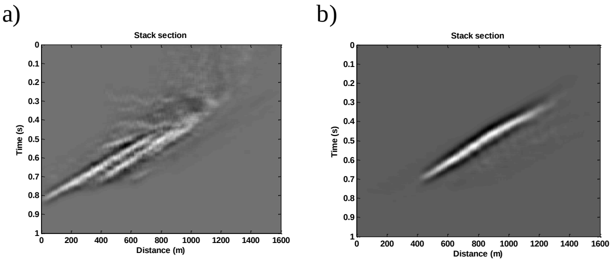

Figure 3. Migration followed by stack results of 60 shot records for the model shown in Figure 2a obtained from a) Equation 1 b) Equation 4.

DISCUSSION

The studied technique in this abstract worked very well for the planer-dipping reflector and in principle should work for the reflectors with very small curvatures. In another word, this method is feasible when there is no rapid change in the shape of geological interfaces. If the change is considerable in a shot record, it would lead to wrong use of zero-offset attributes that do not belong to the seismic energies in each typical point in x-t domain.

To find the velocity in each point, we should be able to find the corresponding zero-offset attributes in a common source gather, specifically when there are conflicting hyperbolic events. In the previous example, as we had just one event per record, it was not difficult to point out zero-offset parameters. We found the maximum amplitude index in the zero-offset trace and used the relevant attributes for all points in common shot domain. We recently find an equation and algorithm to find the attributes in each point in the domain. Equation 7 shows the relationship between zero-offset travel time (t_0) and the corresponding zero-offset slope (p_{x0}).

$$t_0 = \frac{-hp_{x0}+\sqrt{h^2 p_{x0}{}^2+4t^2-4p_x ht}}{2} \quad (7)$$

The following flowchart shows a schematic explanation for the zero-offset scanning algorithm. t_{0i} and p_{x0i} belong to zero-offset travel time and zero-offset slope in each point (i) in the zero-offset trace. Assume that local slopes (p_x) are calculated in whole common shot space. Standing in each point in the space, we have three known variables; two way travel time (t), offset (h) and the local slope (p_x). After substitution of known variables in Equation 7, still there are two unknown parameters; t_{0i} and p_{x0i}. If N is the number of samples in each trace, substitution of all the calculated values for p_{x0i} into the equation give N possible values for zero-offset travel time for that point (t_{0i}'). If we multiply each p_{x0i} to the corresponding calculated t_{0i}' (k_i'=$p_{x0i}\times$ t_{0i}') and subtract each ki' from ki, which is the multiplication of p_{x0i} to its relevant t_{0i} (k_i= $p_{x0i}\times$ t_{0i}), the minimum result of subtraction guides us to the appropriate zero-offset attributes for the point in common shot domain. The zero-offset scanning algorithm can be summarized as the flowchart shown in Figure 4.

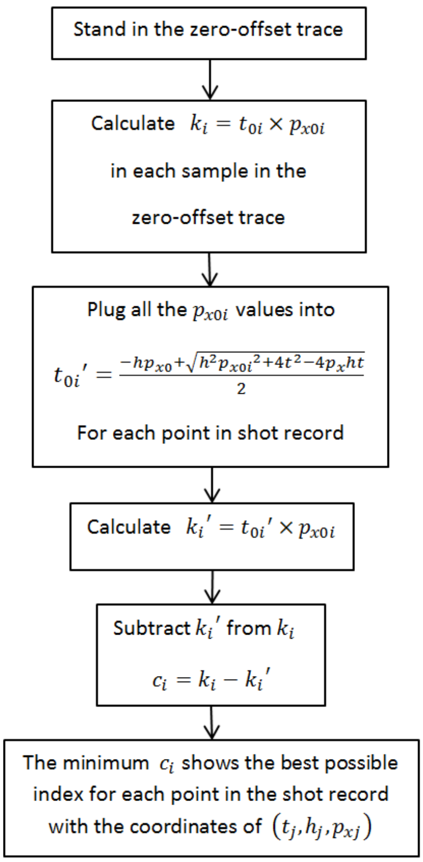

Figure 4. Zero offset scanning flowchart in common shot domain.

Figure 5 indicates the result of zero-offset attribute scanning for one of the synthetic shot records used in the example. As can be seen, zero-offset travel time is found for each point within the seismic event. For example, every point on the top, middle and the bottom of the event has the same colors. Colors show the zero-offset travel time in each point. To scan the attributes in this example, we used exact values for local slopes obtained from move-out equation that we used to generate the data. This zero-offset scanning algorithm should be tested on multi-layer model to be demonstrated in the future work.

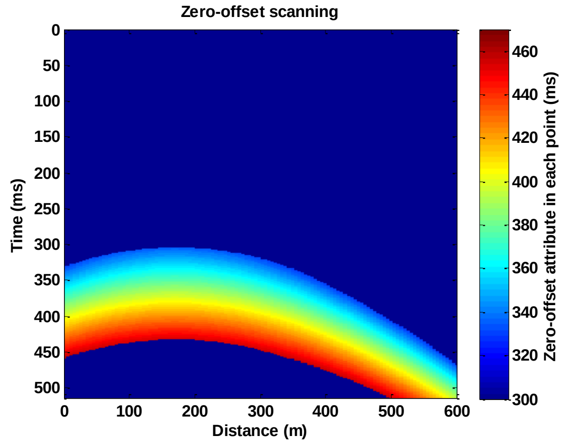

Figure 5. Zero offset attributes scanning for a shot record generated based on the model shown in Figure 2a.

CONCLUSIONS

In this abstract, we presented a new time effective technique to obtain the velocity model using the local slopes in common source domain. There were three main advantages over some previous techniques. First, the technique does not need the seismic data to be sorted in two domains. Second, velocity analysis and imaging were done at the same time. Last but not least, one order of differentiation has been reduced from the previous velocity analysis in in common source domain, using zero-offset attributes. The accuracy of the obtained velocity models in the shown examples was more considerable than the previous technique because of the reduction in order of the derivatives needed. We discussed about the potential limitations and also introduced an algorithm for zero-offset attributes scanning. Our next afford is to use the scanning technique to apply the velocity analysis method on multi layered model and datasets.

ACKNOWLEDGMENTS

The work has been supported by the Deep Exploration Technologies Cooperative Research Centre whose activities are funded by the Australian Government's Cooperative Research Centre Program. This is DETCRC document 2014/457. We thank Madagascar group for their open-source seismic imaging package, specifically Dr. Sergey Fomel for his help and useful suggestions.

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