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Dip-moveout processing: A tutorial Part 1: DMO basics

Alexander M. Popovici[1]

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INTRODUCTION

The Dip Moveout correction (DMO) is an intermediate processing step which when applied together with the Normal Moveout correction (NMO) transforms a constant-offset section into a zero-offset section. There are many benefits to introducing the DMO processing step. By applying the succession of DMO, NMO, stacking and zero-offset migration we replace the more expensive sequence of prestack migration for each offset and stacking. However the migration to zero-offset is not the only improvement that DMO delivers to the seismic section. A list of DMO promises is given by Deregowski (1986) and includes improvement of velocity analysis, dead traces interpolation, improvement of cross-line ties, steep dip coherent noise attenuation, improvement of the signal to noise ratio, diffraction preservation, etc. These beneficial effects will be discussed further in the chapter.

The need for DMO

The need for Dip Moveout appeared from the problem of stacking traces that share the same Common-Mid-Point (CMP). The CMP Stacking assumes that reflections come from horizontal layers. Under this assumption the Normal Moveout correction (NMO) flattens the hyperbolas in a CMP gather to horizontal lines. After NMO, traces belonging to the same CMP are summed together (stacked) to enhance the reflected signal and to attenuate the noise.

Problems appear when dipping events are present in a section. A dipping reflector in a CMP section also appears as a hyperbola (see Figure 1a). The NMO velocity necessary to flatten the hyperbolas originating from reflections on the dipping layer is higher than the real velocity. Applying the NMO correction with the velocity necessary to flatten this hyperbola will misplace the position of the dipping reflector.

Figure **??**a shows several CMP gathers containing reflections from a dipping layer and from a horizontal layer. After NMO with the **real velocity** the hyperbolas cor-

[1]**email:** not available

responding to the flat layer become straight lines (Figure **??**b) and after stacking, the horizontal event is preserved at the expense of the dipping event. In Figure **??**b NMO is performed with a **higher velocity** which is necessary to flatten the hyperbolas corresponding to the dipping event. After stacking (Figure **??**c) the dipping event is preserved at the expense of the horizontal layer. It is obvious that the NMO correction with a single velocity combined with CMP stacking acts as a dip filter. The result is a degradation of the final image when conflicting dips are present.

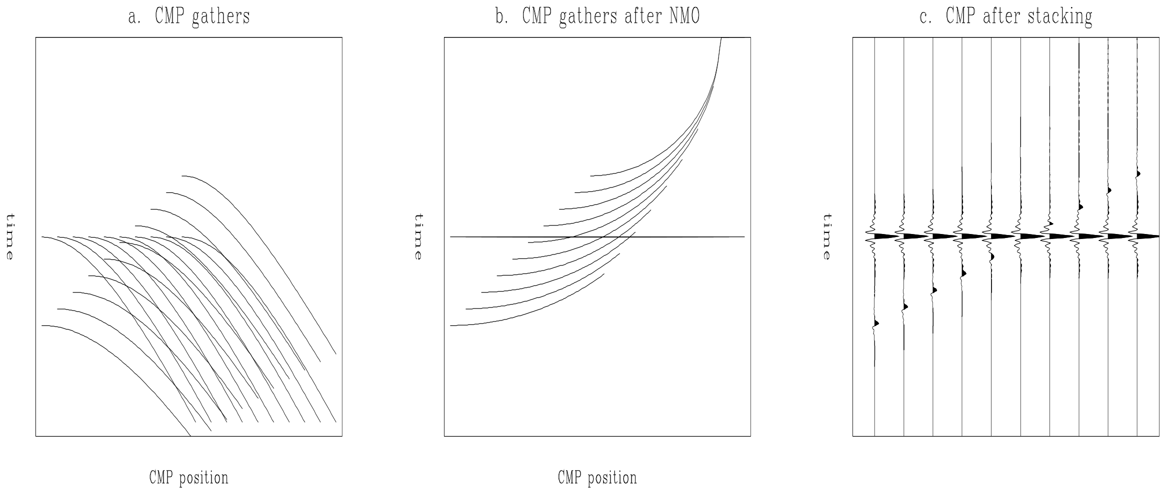

Figure 1: The effect of CMP stacking with real velocity on **dipping reflectors**.
a. Several CMP gathers for a flat layer and a dipping layer.
b. The CMP gathers after NMO with medium velocity (v_{real}); the hyperbolas from the horizontal event are flattened.
c. Traces after stacking for the same CMP.

The NMO velocity

Figure **??** shows a dipping reflector and the position of the source, geophone and CMP. The constant-offset traveltime from the source at point **A** to the receiver at point **B** is represented by the segments **AR**+**RB**. The zero-offset traveltime from the CMP to the reflector and back is given by the segment **FG**. The dipping reflector serves as the axis of symmetry for the figure.

For the geometry in Figure **??** we have

$$\mathbf{AC} = \mathbf{AR} + \mathbf{RB} = vt_h$$

where v is the velocity of the medium and t_h is the shot-receiver traveltime. The segment **FG** (which has the length of the zero-offset raypath) is equal to the segment **AE**. From Figure **??**

$$\mathbf{FG} = (\mathbf{AD} + \mathbf{BC})/2 = \mathbf{BC} + \mathbf{ED} = \mathbf{AE}.$$

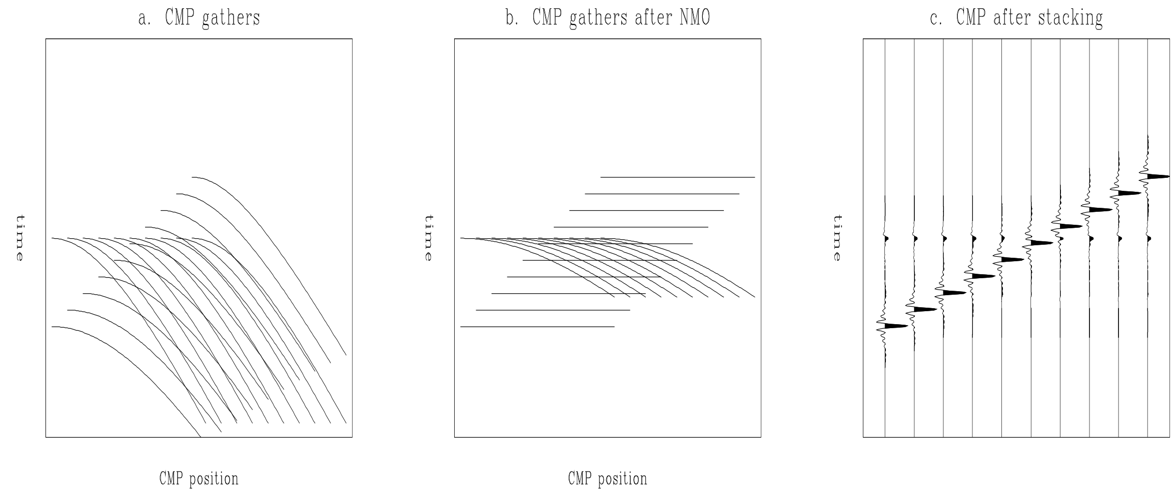

Figure 2: The effect of CMP stacking with velocity ($v_{nmo} = v_{real}/\cos\theta$) on **horizontal reflectors**.
a. Several CMP gathers for a flat layer and a dipping layer.
b. The CMP gathers after NMO with higher velocity; the hyperbolas from the dipping event are flattened.
c. Traces after stacking for the same CMP.

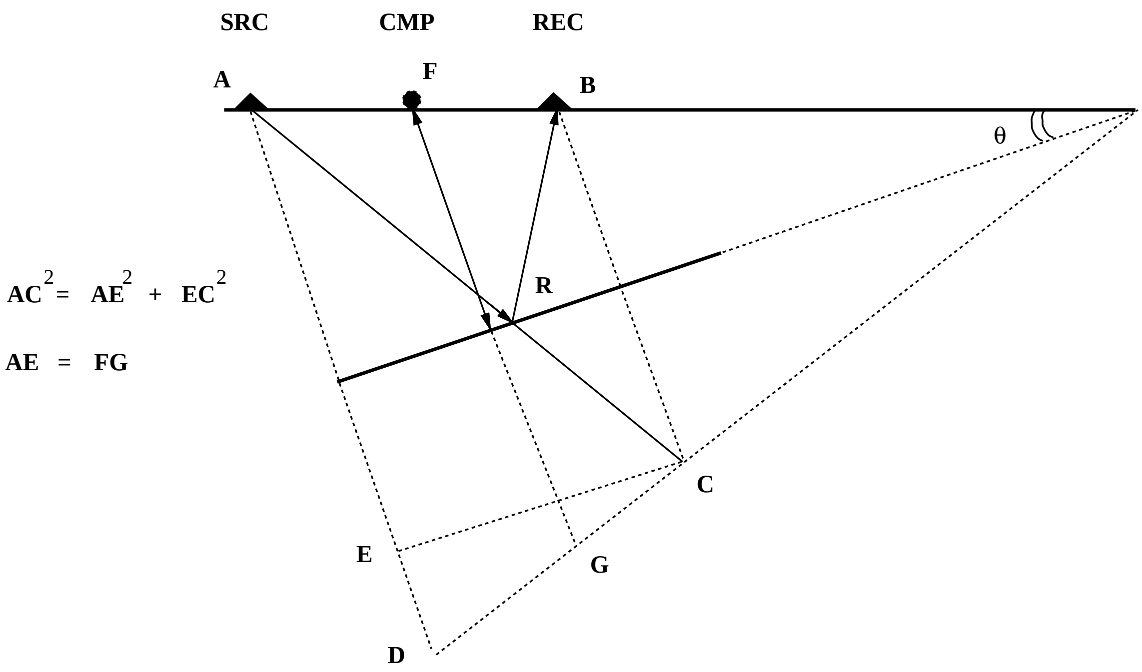

Figure 3: A dipping reflector in a constant velocity medium. The dipping angle is θ. The raypath from the source to the receiver is sketched by the segments **AR** and **RB**. The zero-offset raypath is equal to the segment **FG**.

From the triangle $\triangle\mathbf{AEC}$ we have

$$\mathbf{FG}^2 = \mathbf{AE}^2 = \mathbf{AC}^2 - \mathbf{EC}^2 = (vt_h)^2 - (2h\cos\theta)^2 \tag{1}$$

where θ is the angle of the dipping reflector and $2h$ is the distance between source and receiver. Finally, by dividing the segments with the velocity we have the zero-offset traveltime from the CMP to the reflector:

$$t_0^2 = t_h^2 - \left(\frac{2h\cos\theta}{v}\right)^2 = t_h^2 - \left(\frac{2h}{v_{nmo}}\right)^2. \tag{2}$$

From equation (2) we easily see that the expression for t_h is a hyperbola, with the top at t_0. The NMO velocity necessary to flatten the hyperbola for a dipping reflector is

$$v_{nmo} = \frac{v}{\cos\theta}. \tag{3}$$

DMO and NMO

The Dip Moveout correction (DMO) is in fact an extension to the NMO correction when dips are present. In the presence of only horizontal layers NMO tries to correct the effect of the offset and transform all the constant-offset section into zero-offset section. You can understand the DMO correction as doing exactly the same thing not only for horizontal events but also for dipping events. DMO is an intermediate processing step which attempts to position the conflicting dips in the correct zero-offset location such that after NMO, CMP stacking will not attenuate crossing events.

These concepts are all formulated for a constant velocity medium. For a variable velocity medium the transformation from constant-offset to zero-offset performed by NMO combined with DMO can not be split into two separate processes; instead it forms a single step process called Migration to Zero-Offset (MZO). In constant velocity media $MZO = NMO \cdot DMO$.

To define the parameters involved in the DMO correction we need to analyze the kinematics of the constant-offset reflection of a dipping layer. For a horizontal layer, the reflection point is situated right under the location of the common-midpoint (CMP). For the dipping layer sketched in Figure **??** the reflection point for the source-receiver ray is **R**. This point is positioned updip relative to the intersection **O** of the zero-offset ray from the common-midpoint **F** with the dipping reflector.

In a constant-offset section the trace corresponding to a source positioned at point **A** and a receiver positioned at point **B** is placed in the location of the CMP. However in a zero-offset experiment the reflection point **R** is observed from the surface position **J**. Migration to zero-offset ($NMO \cdot DMO$) is the transformation which relocates a reflection point as seen in constant-offset to a place corresponding to the reflection point as seen in zero-offset.

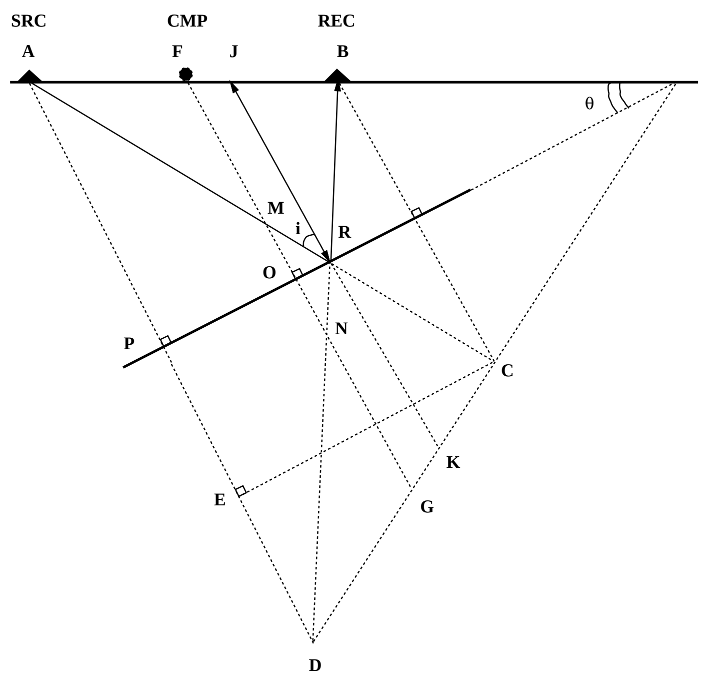

Figure 4: DMO kinematics. A dipping reflector in a constant velocity medium. The dipping angle is θ. The raypath from the source to the receiver is sketched by the segments **AR** and **RB**. The reflection point **R** is seen in the zero-offset case from the surface point **J**. The zero-offset raypath from **J** is equal to the segment **JK**. The incidence angle at **R** is i.

In order to define the operator we have to calculate the time correction and the surface coordinate correction to transform a constant-offset section into a zero-offset section. In Figure **??** the segment **JR** represents the zero-offset ray from the reflection point **R**. The segment **FJ** represents the surface correction from the CMP to the real zero-offset position of both the source and receiver. We can calculate the surface correction and the traveltime correction using some elementary geometry.

The source-receiver traveltime t_h corresponds to the ray path **ARB**. The velocity of the medium is v and the constant-offset traveltime is

$$t_h = \frac{(\mathbf{AR} + \mathbf{RB})}{v}.$$

The segment **AB** represents the offset between the source and receiver and we have

$$\mathbf{AF} = \mathbf{FB} = \frac{\mathbf{AB}}{2} = h.$$

The segment **AC** is equal to **AR** +**RB** and therefore $\mathbf{AC} = vt_h$.

From Figure **??** we observe that the most important equation relating the angle of the dipping reflector and the incidence angle of the constant-offset raypath is

$$2h \cos\theta = vt_h \sin i = \mathbf{EC}, \tag{4}$$

where θ is the dipping angle of the reflector and i is the incident angle of the constant-offset raypath at the reflection point **R**. From equation (4) we have

$$\cos i = \frac{1}{vt_h}\sqrt{(vt_h)^2 - (2h\cos\theta)^2}.$$

To calculate the segment $x_0 = \mathbf{FJ}$ which is the DMO surface correction we note that

$$x_0 = \frac{\mathbf{OR}}{\cos\theta}$$

and

$$\mathbf{OR} = \mathbf{MO}\tan i.$$

The segment **MN**$= 2$**MO** is easily calculated as half the difference between the bases of the trapezoid **ABCD**. We have

$$\mathbf{MO} = \frac{\mathbf{MN}}{2} = \frac{\mathbf{AD} - \mathbf{BC}}{4} = h\sin\theta \tag{5}$$

and finally

$$x_0 = h\sin\theta\frac{\tan i}{\cos\theta} = \frac{2h^2\sin\theta}{\sqrt{(vt_h)^2 - (2h\cos\theta)^2}}. \tag{6}$$

Knowing segment **FJ**, the zero-offset traveltime given by the segment **JK** is calculated as

$$\mathbf{JK} = \mathbf{FG} - 2\mathbf{FJ}\sin\theta.$$

The segment **FG** is expressed in equation (1)

$$\mathbf{FG} = \sqrt{(vt_h)^2 - (2h\cos\theta)^2}.$$

Therefore we have

$$t_0 = \frac{\mathbf{JK}}{v} = \frac{(vt_h)^2 - (2h)^2}{v\sqrt{(vt_h)^2 - (2h\cos\theta)^2}}. \tag{7}$$

We have obtained the parametric equations defining the $NMO \cdot DMO$ operator in constant velocity media:

$$\begin{cases} x_0 = \dfrac{2h^2\sin\theta}{\sqrt{(vt_h)^2 - (2h\cos\theta)^2}} \\[2ex] t_0 = \dfrac{(vt_h)^2 - (2h)^2}{v\sqrt{(vt_h)^2 - (2h\cos\theta)^2}}. \end{cases} \tag{8}$$

The formulas in equation (**??**) tell us where an event from a constant-offset section is moved in a zero-offset section when the dip is known. However we will see later that the dip doesn't have to be known to correctly apply the DMO operator. Figure **??** shows the variation of t_0 and x_0 for a whole range of dips. For a zero dip we have

$$\begin{cases} x_0 = 0 \\[2ex] t_0 = \sqrt{t_h^2 - \left(\dfrac{2h}{v}\right)^2} \end{cases}$$

which is just the NMO correction.

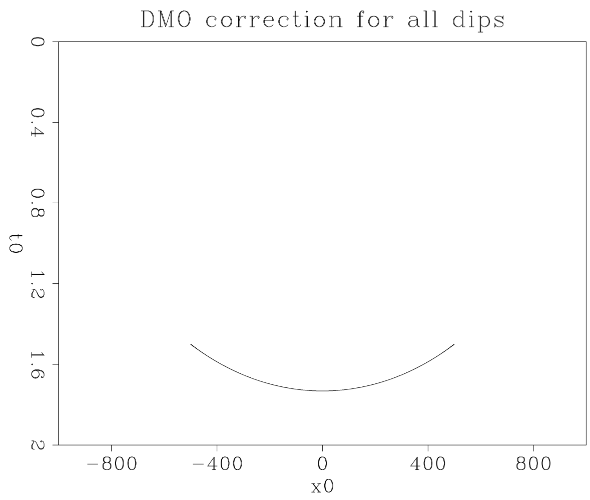

Figure 5: The distribution of the DMO correction for all dips $(\frac{-\pi}{2} \leq \theta \leq \frac{\pi}{2})$.

How DMO works

The goal of the $NMO \cdot DMO$ processing step is to transform a constant-offset section into a zero-offset section. We can conceive any structure (or depth model) as composed of independent diffractors. This is the commonplace assumption for Kirchhoff migration. By summing the contributions from all the diffractors we can obtain our constant-offset section. Following this hypothesis it is interesting to examine the behavior of a single diffraction curve in constant-offset. Figure 6 shows a **constant-offset** diffraction curve together with a **zero-offset** diffraction curve which is actually a hyperbola. The aim of the $NMO \cdot DMO$ step is to transform the former into the latter.

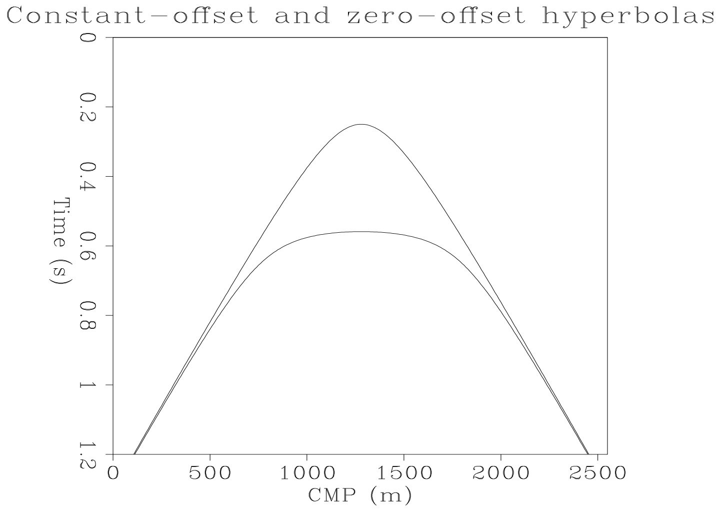

Figure 6: Zero-offset hyperbola and the constant-offset diffraction curve.

Figure 7 shows the kinematics of the $DMO \cdot NMO$ operator; each point along the constant-offset diffraction curve is spread along an operator similar to the one shown in Figure 5 and using equation (8). The result of this operation is displayed on the right side in Figure 7. The artifacts at the top of the figure are due to the constant amplitude assigned along the DMO curve. In reality the amplitude along the DMO curve is tapered toward the end of the operator, as will be shown in the next chapters.

Problem 1.

Demonstrate that for the geometry presented in Figure **??** we have the following equality:

$$\frac{\mathbf{AD}}{\mathbf{FG}} = \frac{\mathbf{JK}}{\mathbf{BC}}.$$

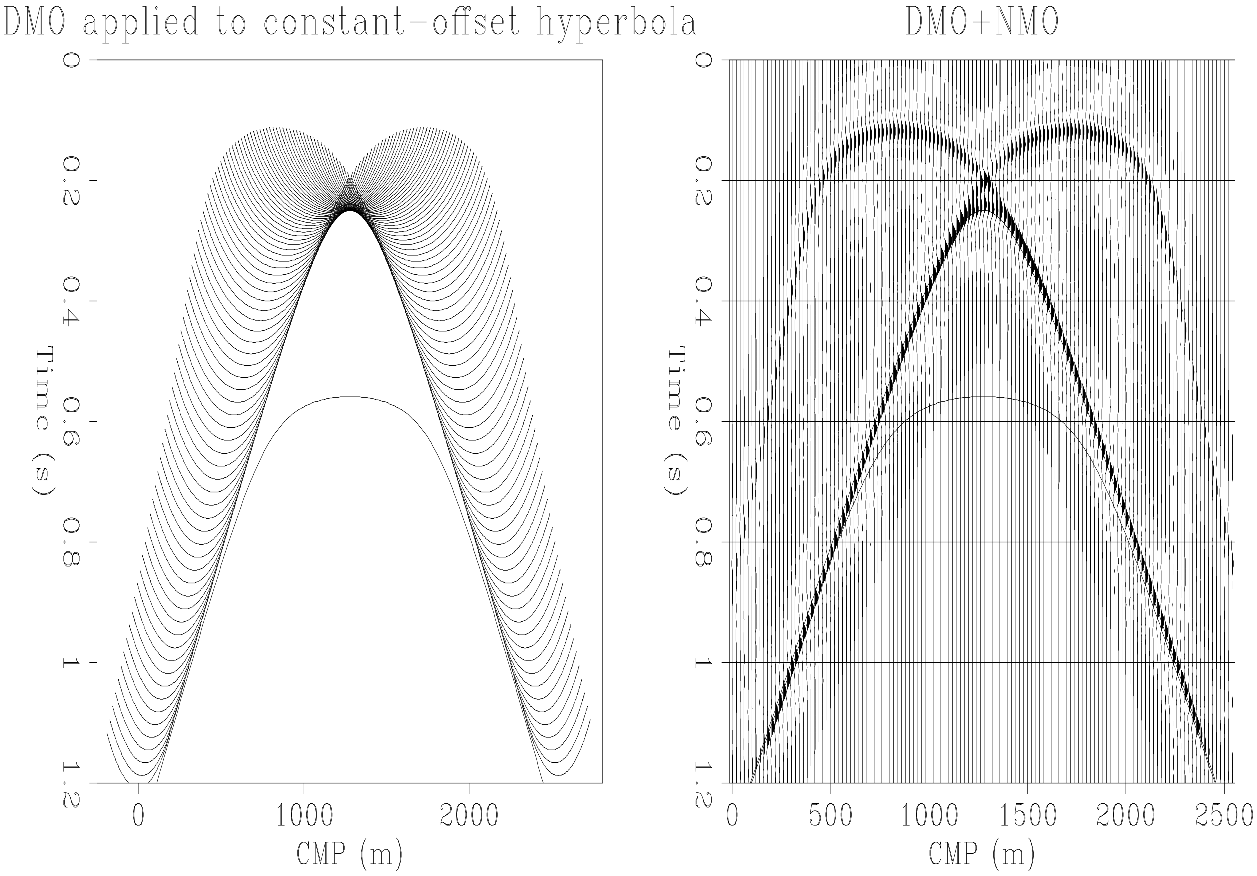

Figure 7: $NMO \cdot DMO$ transforms a constant-offset diffraction curve to a zero-offset hyperbola.
(LEFT) $NMO \cdot DMO$ kinematics; each point on the constant-offset diffraction curve is spread along the DMO curve and shifted with the NMO correction.
(RIGHT) The result of applying $NMO \cdot DMO$ to the constant-offset hyperbola. The artifacts are due to using a constant amplitude along the DMO curve.

Problem 2.

For the geometry presented in Figure **??** and using equation (**??**) show that the reflection point displacement measured along the reflector is

$$\mathbf{OR} = \frac{h^2}{t_{cmp}} 2 \sin\theta \cos\theta$$

where t_{cmp} is the traveltime from the CMP location (point **F**) to the reflector and back (or the segment **FG** in time units). The length of the segment **FG** is given in equation (**??**). This equation appears in Levin's (1971) classic paper, and is also the first equation Dave Hale uses when explaining DMO in his SEG course notes.

More DMO kinematics

We defined DMO as an operator which together with NMO transforms data from constant-offset to zero offset. After Zero-Offset Migration (ZOM) the result of our data processing sequence is equal to the output of Prestack Migration (PsM). We can write this in a formal form

$$(NMO \cdot DMO)(ZOM) = MZO \cdot ZOM = PsM.$$

Using this definition we can describe the sequence $NMO \cdot DMO = MZO$ as

$$MZO = PsM \cdot ZOM^{-1} \tag{9}$$

where the MZO operator can be built using the Prestack Migration operator and the inverse of the Zero-Offset Migration operator, which is the Zero-Offset Modeling.

We use this definition to define a MZO operator not only for a constant velocity medium, but for any variable velocity medium. The impulse response of the generalized $NMO \cdot DMO$ can be defined by a two step process:

1. **Full prestack migration to a depth model**. The prestack depth model is the position in space of all points that can generate a given impulse in a constant-offset section. For a constant velocity medium this is equivalent to constructing the migration ellipse for a constant-offset section. For a variable velocity medium, the loci of points with equal travel-time from source to receiver form a curve resembling an ellipse or a superposition of several ellipses.

2. **Zero-offset modeling**. Given the depth model, raytrace back at 90 degrees from the reflector, to model the zero-offset data. The intersection of the ray with the surface will give the x-coordinate of the MZO operator, while the travel-time along the raypath will provide the zero-offset time-coordinate.

Using this definition we can find another path to derive analytically the DMO operator in constant velocity media.

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