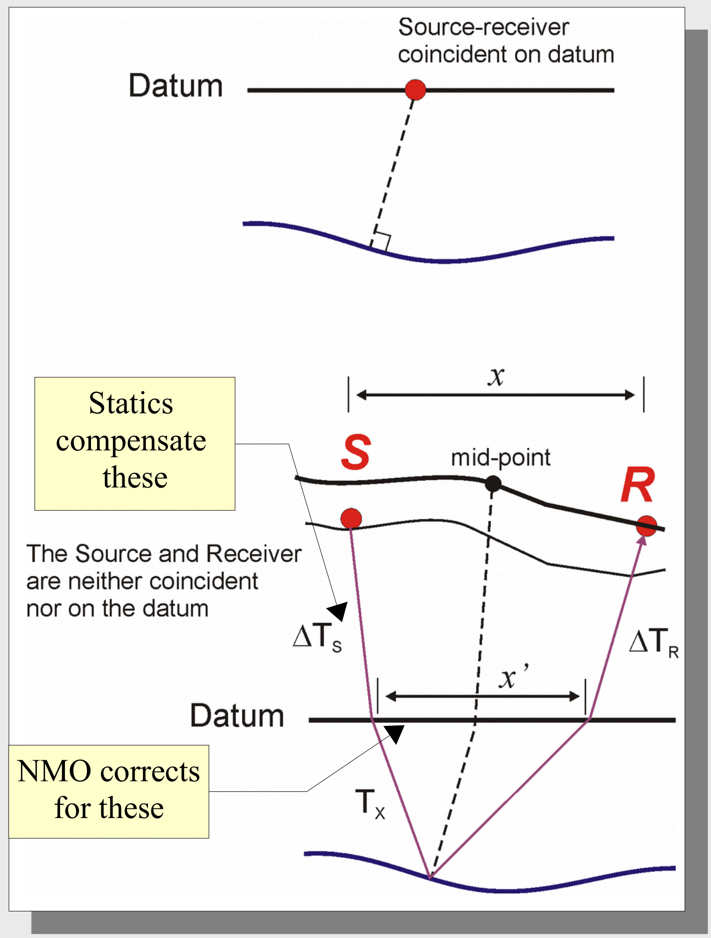
Geometrical Seismics
Reflection

- Normal moveout (NMO)
- Normal moveout correction
- Dip moveout (DMO)

- Reading:
  - Sheriff and Geldart, Chapter 4.1.

Zero-Offset Section
(*The goal of reflection imaging*)

- **The Ideal of reflection imaging** *is sources* and receivers *collocated* on a flat horizontal surface ("*datum*").
- In reality, however, we record at *source-receiver offsets*, and over complex topography.
- **Two types of corrections** are applied to compensate these factors:
    - Statics "place" sources and receivers onto the datum;
    - Normal Moveout Corrections "transforms" the records into as if they were recorded at collocated sources and receivers.



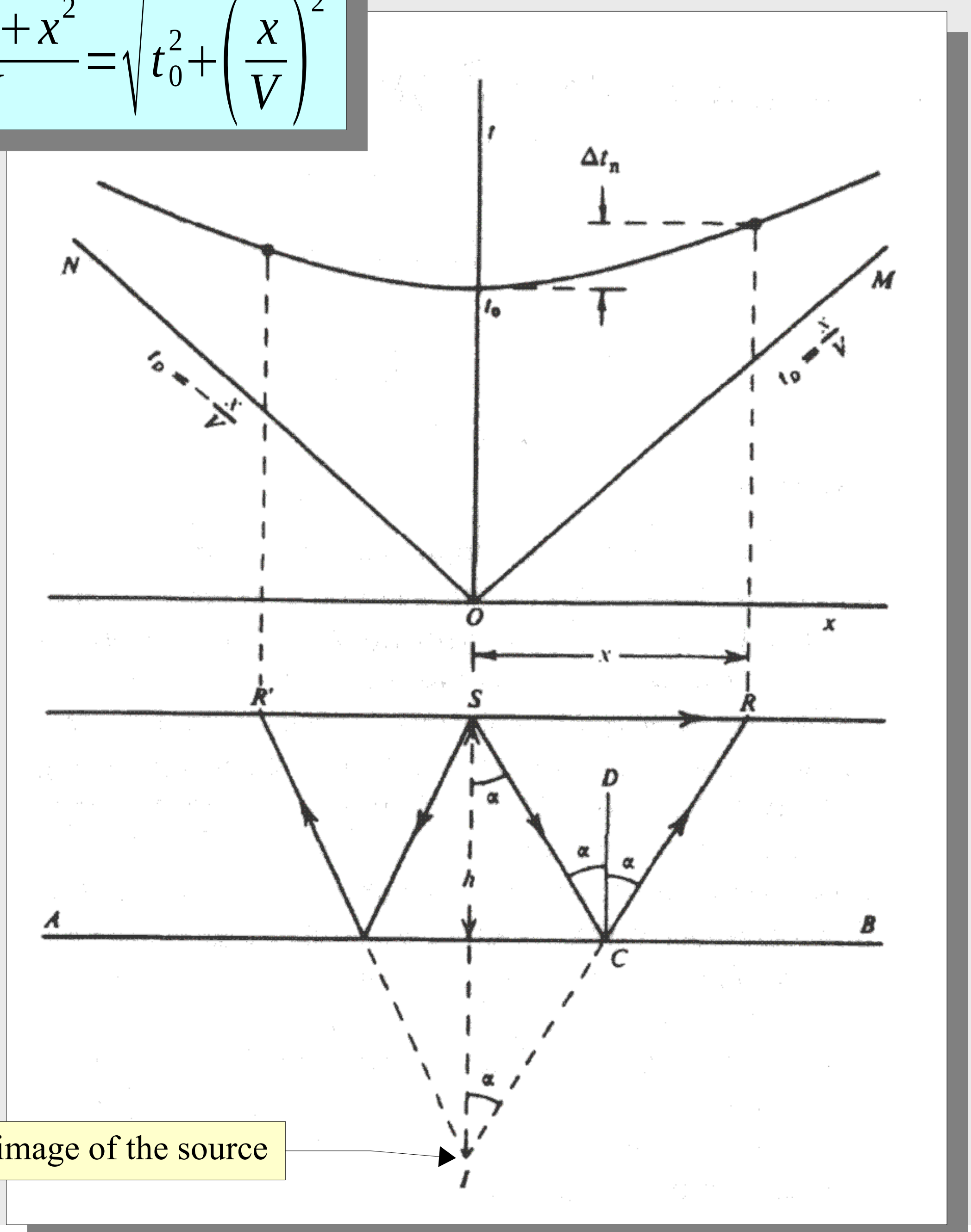
- **As a result** of these corrections (plus stacking to attenuate noise), we obtain a *zero-offset section*.

Normal moveout

New!

- Symmetrical hyperbola
- Reflected rays propagate as if from a source at depth

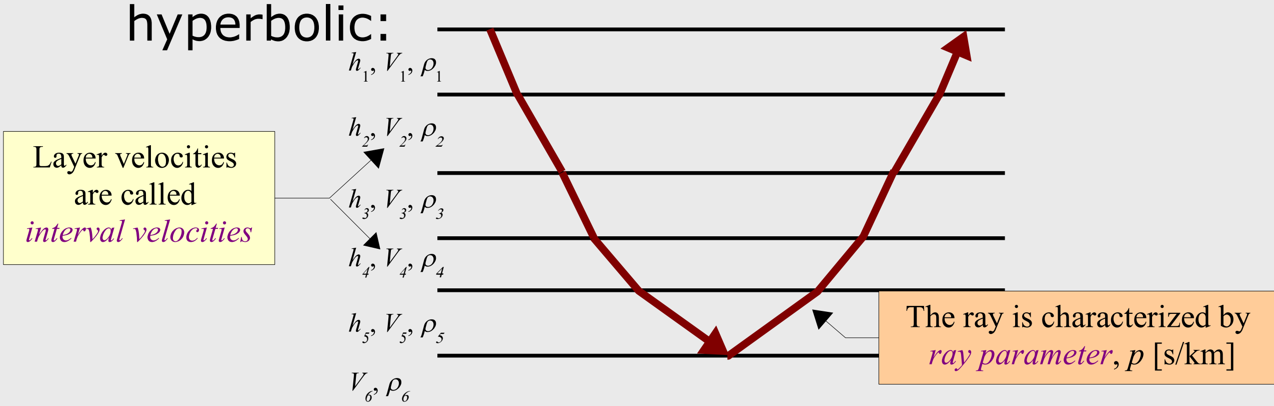
$$t(x)=\frac{\sqrt{4\mathrm{h}^2+x^2}}{V}=\sqrt{t_0^2+\left(\frac{x}{V}\right)^2}$$



Mirror image of the source

Reflection travel-times
(*Multiple layers*)

- For multiple layers, $t(x)$ is no longer hyperbolic:



- For practical applications (near-vertical incidence, pV_i<<1), $t(x)$ still can be approximated as:

$$x_n(p)=\sum_{i=1}^{n}\frac{h_i p V_i}{\sqrt{1-(pV_i)^2}}\approx p\sum_{i=1}^{n}h_i V_i\left[1+\frac{1}{2}(pV_i)^2\right]\approx p\sum_{i=1}^{n}h_i V_i,$$

hence: $$p=\frac{x_n(p)}{\sum_{i=1}^{n}h_i V_i},$$

$$t_n(p)=\sum_{i=1}^{n}\frac{h_i}{V_i\sqrt{1-(pV_i)^2}}\approx\sum_{i=1}^{n}\frac{h_i}{V_i}\left[1+\frac{1}{2}(pV_i)^2\right]=t_0+\frac{1}{2}p^2\sum_{i=1}^{n}h_i V_i$$

$$t_n(x)\approx t_0+\frac{1}{2t_0}\left(\frac{x}{V_{RMS}}\right)^2$$

- here, V_{RMS} is the RMS (root-mean-square) velocity:

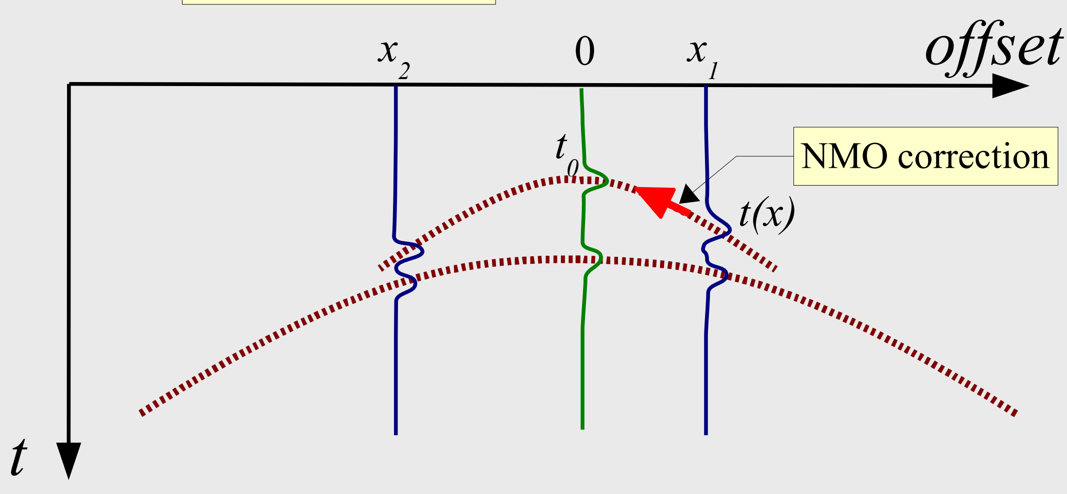
$$V_{RMS}=\sqrt{\frac{\sum_{i=1}^{n}h_i V_i}{t_0}}=\sqrt{\frac{\sum_{i=1}^{n}t_i V_i^2}{\sum_{i=1}^{n}t_i}}.$$

Normal Moveout (NMO) correction

- NMO correction transforms a reflection record at offset *x* into a normal-incidence (*x*=0) record:

$$t(x) \rightarrow t_0 = \sqrt{t^2(x) - \left(\frac{x}{V}\right)^2} \approx t(x) - \frac{1}{2t(x)}\left(\frac{x}{V}\right)^2$$

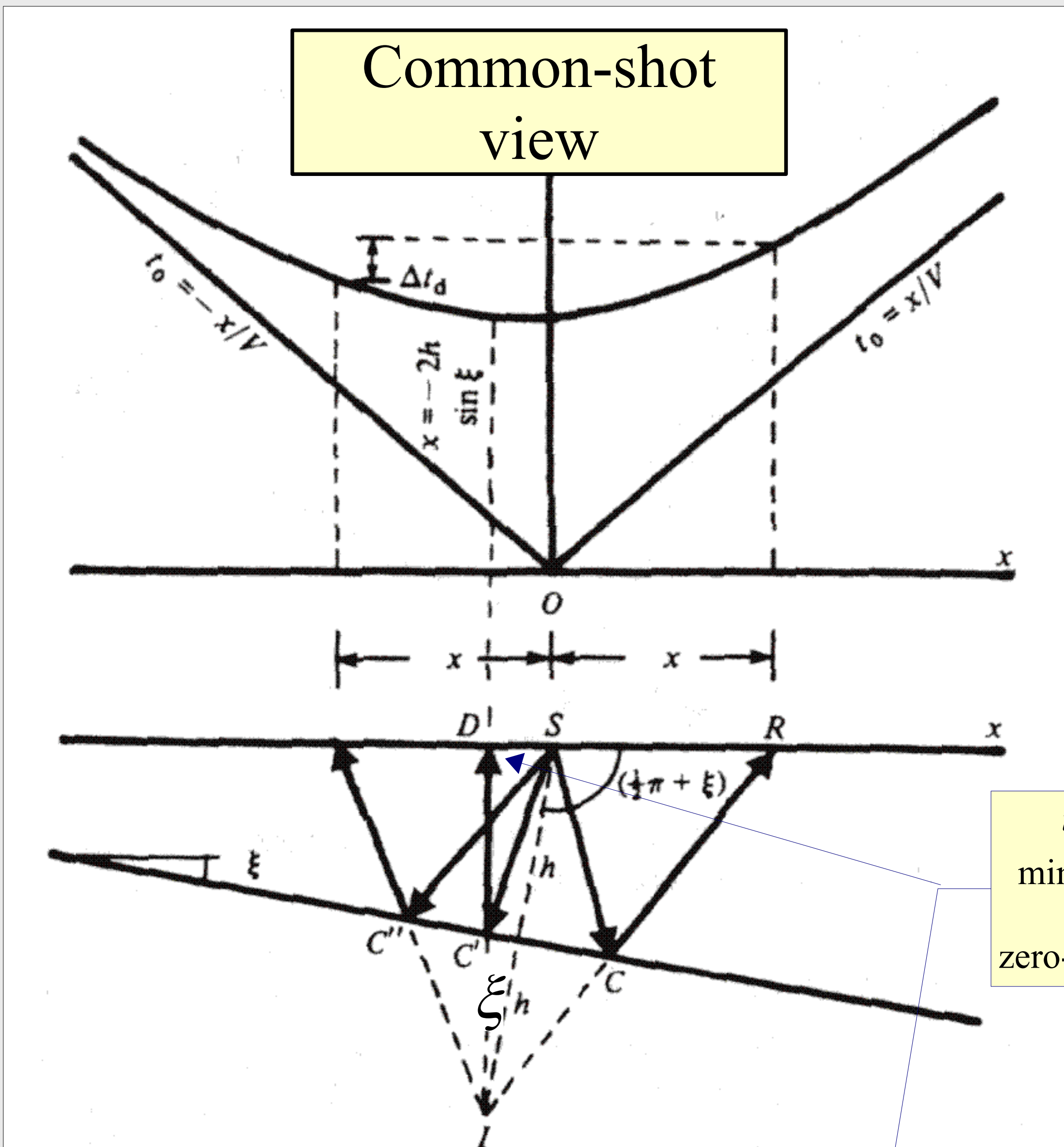
"Stacking velocity"



- *Stacking velocity* is determined from the data, as a parameter of the reflection hyperbola that is best aligned with the reflection event
- Note that NMO correction affects the shallower and slower reflections stronger
  - This is called "*NMO stretching*"

Dipping reflector New!

- Hyperbola of the same shape but with the apex shifted up-dip
- Asymptotically the same moveouts



t_0 is the minimal time, not the zero-offset time!

$$t(x)=\frac{\sqrt{(2h\cos\xi)^2+(x+2h\sin\xi)^2}}{V}=\sqrt{t_0^2+\left[\frac{(x+2h\sin\xi)}{V}\right]^2}$$

New!

Dip moveout

- For small offsets ($x << h$) and dips ($h \sin \xi << x$):

Note: $2h = t_0 V$

$$t(x) = \sqrt{t_0^2 + \left[\frac{(x + 2h \sin \xi)}{V}\right]^2} \approx t_0 \left[1 + \frac{x^2 + 4hx \sin \xi}{2(t_0 V)^2}\right].$$

$$t(x) \approx t_0 + \frac{x^2}{2t_0 V^2} + \frac{x \sin \xi}{V}.$$

Apex ≈ Zero-offset time

Normal moveout term

Dip moveout term

- Reflector dip ξ can be measured from the *dip moveout*:

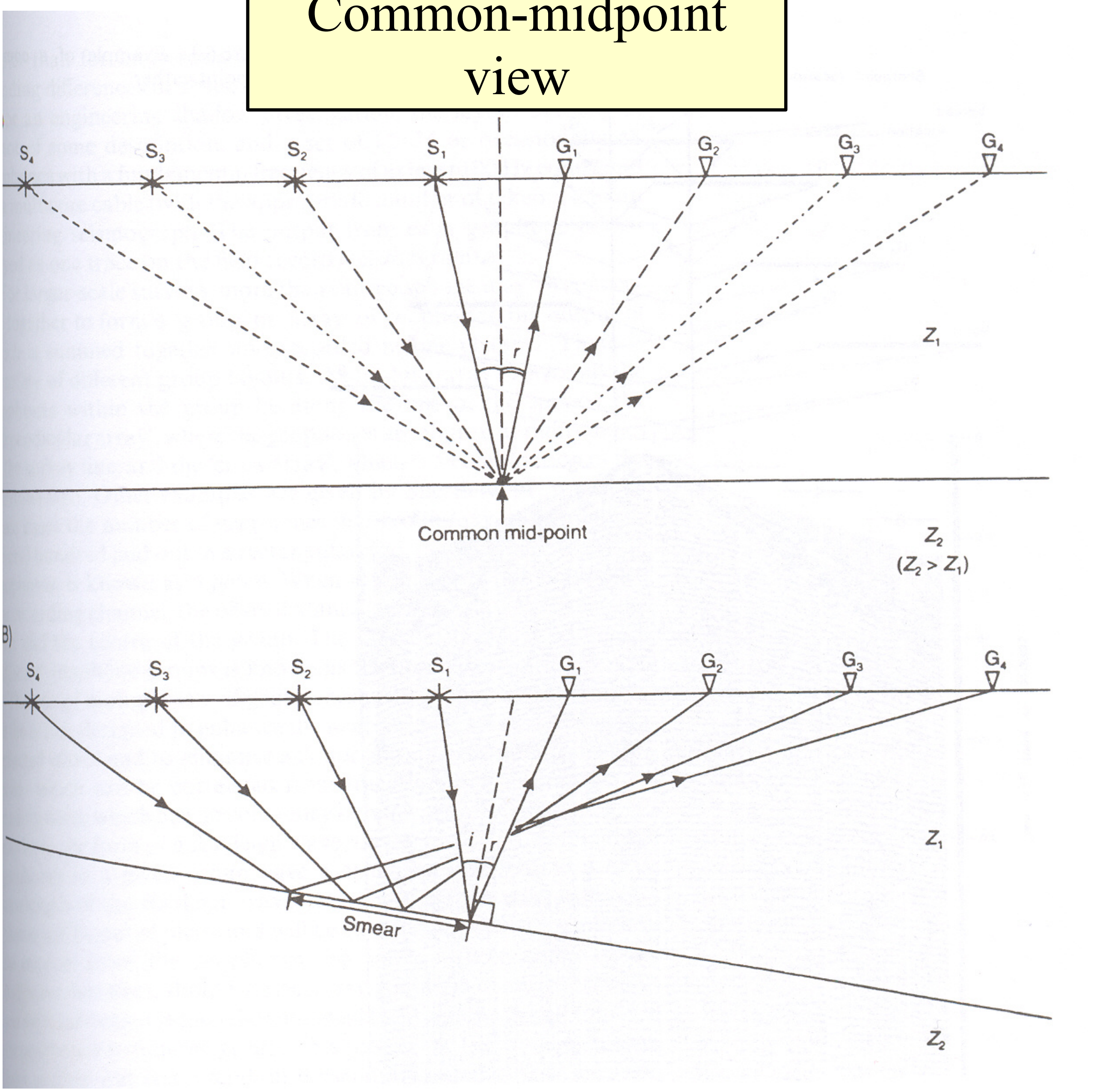
$$\sin \xi \approx \frac{V}{2} \frac{t(x) - t(-x)}{x} \equiv \frac{V}{2} \boxed{\frac{t_{Downdip} - t_{Updip}}{x}}.$$

This ratio is also called *Dip Moveout*

Dip moveout in CMP gathers

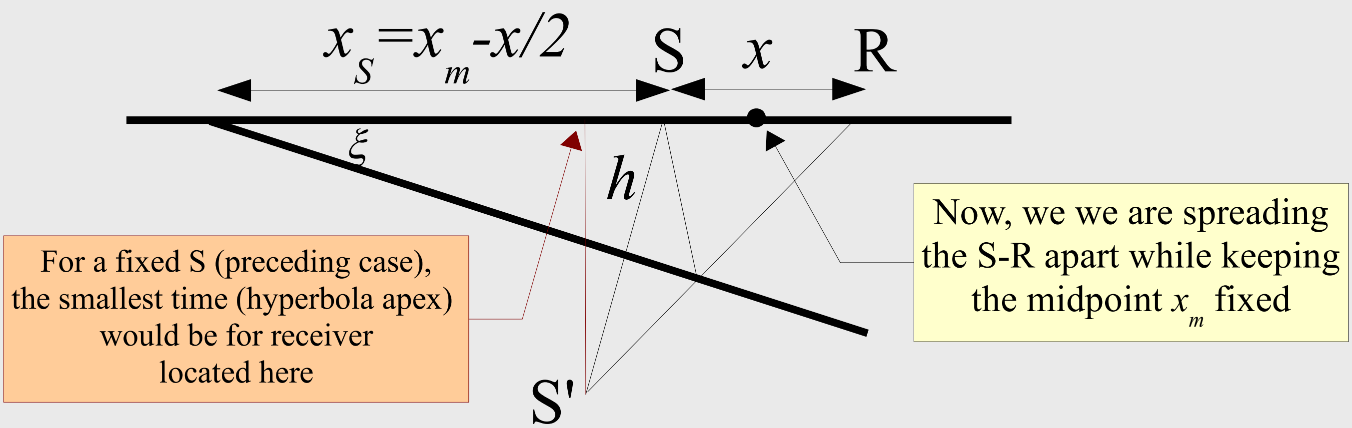
- The travel-time hyperbola becomes ***symmetrical***
- Reflection points are ***smeared*** up-dip with increasing offset
- Asymptotic velocities *are* ***greater*** than the true velocity

Common-midpoint view



Stacking velocity in the presence of dip

New!



- For a fixed x_m, the dependence of the S-R time on the offset x is

$$t(x) = \frac{1}{V}\sqrt{(x + 2h\sin\xi)^2 + (2h\cos\xi)^2}$$

$$t(x) = \frac{1}{V}\sqrt{\left[x + (2x_m - x)\sin^2\xi\right]^2 + \left[(2x_m - x)\sin\xi\cos\xi\right]^2}$$

$$t(x) = \frac{1}{V}\sqrt{(2x_m\sin\xi)^2 + (x\cos\xi)^2}$$

continued...

New!

CMP Stacking velocity in the presence of dip (*cont.*)

- This equation describes a hyperbola similar to the NMO equation (compare to: $$t_{NMO}(x)=\sqrt{t_0^2+\left(\frac{x}{V}\right)^2}$$):

$$t(x)=\frac{1}{V}\sqrt{\left(2x_m\sin\xi\right)^2+\left(x\cos\xi\right)^2}=\sqrt{\underbrace{\left(\frac{2x_m\sin\xi}{V}\right)^2}_{\text{Zero-offset time}}+\underbrace{\left(\frac{x\cos\xi}{V}\right)^2}_{\text{Hyperbolic moveout}}}$$

- Thus, because of the dip, the effective velocity is increased:

$$V_{Dip}=\frac{V}{\cos\xi}.$$

- This means that when stacking velocities are measured from a CMP gather, dipping reflectors will result in higher velocities (flatter reflection hyperbola)
- As a result, reflectors with conflicting dips cannot be NMO-corrected and stacked accurately.
  - Processing step called ***DMO*** corrects this problem.