A layer striping approach for estimation of Q Factor and Reflection Coefficient using spectral ratio method

Soumen Deshmukh, M S Rana, Radha Krishna; KDMIPE, ONGC, Dehradun*

soumendeshmukh@gmail.com

Keywords

Seismic Quality Factor (Q), Reflection Coefficient, Spectral ratio method

Summary

Seismic quality factor (Q)is a very useful parameter to shed light on lithology, porosity, and pore fluids etc. Several authors (*Dasgupta, 1998; Sain et al., 2009; Sain and Singh, 2011*) estimated Q from multi-channel seismic data. Here, we present a new approach for estimating Q along with reflection coefficient from offset-dependent amplitude data. Warner (*1990*) tries to get reflection coefficient by taking the ratio of primary and multiple reflection amplitudes. Often multiples are not visible on seismograms and they may lie beyond the record length. To avoid such problems, we propose to calculate the reflections coefficients at lithological boundaries from amplitudes of primary reflections only. The effectiveness of the approach has been demonstrated with a synthetic and real examples. Tests show promise that it determines interval Q values with reasonable accuracy.

Introduction

Seismic waves travelling through the earth experience attenuation due to anelasticity of the medium. Q is also sensitive to lithology, porosity, permeability, and pore fluid characteristicsand affects the amplitude versus offset (AVO) signatures. Thus, estimating Q is very desirable to compensate for the effect for AVO analysis and to understand the fluid characteristics. Laboratory experiments indicate that the Q of a mediumdecreases with the saturation of fluids (*Gardner et al. 1964*) and increases with increasing pressure (*Klima et al. 1969*) and velocity. A saturated or ductile medium has smaller Q than a rigid medium.

Reflection coefficient is directly proportional to seismic impedance contrast which gives an idea of geophysical properties variation of subsurface earth. Reflection coefficient also useful for Archaeological study (*Bull et al., 1998*), Gas-hydrate study, study of global sea level changes etc.

We show a layer striping approach for estimation of Q Factor and Reflection Coefficient using logarithmspectral ratio method from prestack noise free and spherical divergence corrected gathers. The input data are noise free amplitudes and two way times varies with offset of subsequent layers and the dominant frequency of each trace element.

Methodology

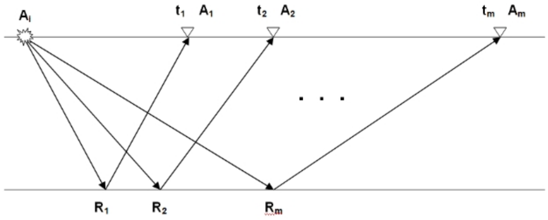

Figure 1: Reflection Coefficients, amplitudes and times at different offset for same sourse.

If there are m no of receivers, than the reflectivity series varies with offset will be:

$$[\,R_{11,}R_{12,}R_{13,}R_{1m}\,]$$

If the amplitudes of each reflected events are geometrical spreading corrected and noise free, than we can write:

$$A_{11} = R_{11} * A_i * e^{-\pi f_{11} t_{11}/Q_1} \quad (1)$$

Where Q_1 is the seismic quality factor for 1st layer, A_i is the incident amplitude, t_{11} is the TWT from 1st interface at receiver 1 and f_{11} is the dominant frequency at receiver 1. Similarly we can write for the 2nd and other receivers as:

$$A_{12} = R_{12} * A_i * e^{-\pi f_{12} t_{12}/Q_1} \quad (2)$$

$$A_{13} = R_{13} * A_i * e^{-\pi f_{13} t_{13}/Q_1} \quad (3)$$

∘

∘

$$A_{1m} = R_{1m} * A_i * e^{-\pi f_{1m} t_{1m}/Q_1} \quad (4)$$

From the above equations we can formulate:

$$A_{11}/A_{12} = R_{11}/R_{12} * e^{-\pi(f_{11}t_{11} - f_{12}t_{12})/Q_1} \quad (5)$$

$$A_{11}/A_{13} = R_{11}/R_{13} * e^{-\pi(f_{11}t_{11} - f_{13}t_{13})/Q_1} \quad (6)$$

∘

∘

$$A_{11}/A_{1m} = R_{11}/R_{1m} * e^{-\pi(f_{11}t_{11} - f_{1m}t_{1m})/Q_1} \quad (7)$$

Taking the logarithm of above equations we get:

$$\log(A_{11}/A_{12}) = \log(R_{11}/R_{12}) + \pi(f_{12}t_{12} - f_{11}t_{11})/Q_1 \quad (8)$$

In simplifies form

$$\log(A_{11}/A_{12}) = \pi(f_{12}t_{12} - f_{11}t_{11})/Q_1 + \log(R_{11}) - \log(R_{12}) \quad (9)$$

$$\log(A_{11}/A_{13}) = \pi(f_{13}t_{13} - f_{11}t_{11})/Q_1 + \log(R_{11}) - \log(R_{13}) \quad (10)$$

∘

∘

$$\log(A_{11}/A_{1m}) = \pi(f_{1m}t_{1m} - f_{11}t_{11})/Q_1 + \log(R_{11}) - \log(R_{1m}) \quad (11)$$

In Matrix form we can write:

$$\begin{bmatrix} log(A_{11}/A_{12}) \\ log(A_{11}/A_{13}) \\ \vdots \\ log(A_{11}/A_{1m}) \end{bmatrix} = \begin{bmatrix} \pi(f_{12}t_{12} - f_{11}t_{11}) & 1 & -1 & 0 & \dots & 0 \\ \pi(f_{13}t_{13} - f_{11}t_{11}) & 1 & 0 & -1 & \dots & 0 \\ & & \ddots & & & \\ \pi(f_{1m}t_{1m} - f_{11}t_{11}) & 1 & 0 & 0 & \dots & -1 \end{bmatrix} * \begin{bmatrix} 1/Q_1 \\ log(R_{11}) \\ log(R_{12}) \\ \vdots \\ log(R_{1m}) \end{bmatrix}$$

m-1 m-1 x m+1 m+1 x1

D = G * M

Where D is the data parameter, M is the model parameter and G is the forward problem operator. Here the no of model parameter (m+1) > no of data parameter (m-1), so it is an underdetermined inverse problem and can be solved by following inverse equation:

$$M = G^T * (G * G^T)^{-1} * D \quad (12)$$

From the above solution we can get the quality factor of 1st layer and the P wave reflection coefficient of consecutive offset for 1st layer.

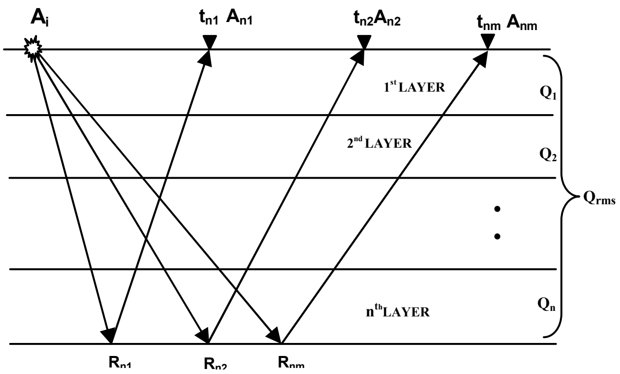

Figure 2: Amplitudes and times at different offset for same sourse for multiple layers(ray bending not considered).

We will use RMS approach for multi-layer study. For multi-layer Q_{rms} is the rms quality factor for n no of layer

$$Q_{rms(n)} = \sqrt{\frac{Q_1^2 t_{01} + Q_2^2 t_{02} + \bullet\bullet + Q_{(n)}^2 t_{0(n)}}{t_{01} + t_{02} + \bullet\bullet + t_{0(n)}}} \quad (13)$$

Where Q_n is the quality factor for n^{th} layer, $t_{0(n)}$ is the zero offset travel time for n^{th} layer. Using layer striping approach we can get the interval quality factor of individual layers.

$$Q_n = \sqrt{\frac{Q_{rms(n)}^2 t_{0(n)} - Q_{rms(n-1)}^2 t_{0(n-1)}}{t_{0(n)} - t_{0(n-1)}}} \quad (13)$$

The amplitude at m^{th} receiver from n^{th} reflector is

$$A_{nm} = R_{nm} * A_i * e^{-\pi f_{nn} t_{nm} / Q_{rms(n)}} \quad (14)$$

Where R_{nm} is the rms reflection coefficient at the base of n^{th} layer.

The matrix equation for single layer approach will give the interval Q for consecutive layers.

Using above equations till now we can estimate the reflection coefficients of 1^{st} layer, rms reflection coefficients of consecutive layers and the interval Q of consecutive layers.

For getting reflection coefficients at each interface we consider ray bending at each interface.

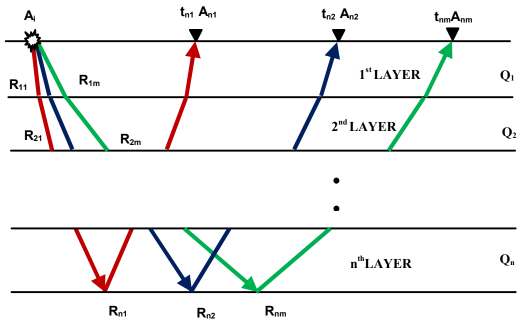

Figure 3: Reflection Coefficients, amplitudes and times at different offset for same sourse for multiple layers(ray bending considered).

The amplitude at 1^{st} receiver from n^{th} reflector can be written as

$$A_{n1} = R_{n1} * \left(\sum_{1}^{n-1}\left(1 - R^2_{(n-1)1}\right)\right) * A_i * e^{\frac{\pi f_{n1} t_{n1}}{Q_{rms(n)}}} \quad (15)$$

The amplitude at m^{th} receiver from n^{th} reflector can be written as

$$A_{nm} = R_{nm} * \left(\sum_{1}^{n-1}\left(1 - R^2_{(n-1)m}\right)\right) * A_i * e^{\frac{\pi f_{nm} t_{nm}}{Q_{rms(n)}}} \quad (16)$$

$$\text{Or,} A_{nm} = R_{nm} * A_i * K_{nm} \quad (17)$$

Where

$K_{nm} = \left(\sum_1^{n-1}\left(1 - R^2_{(n-1)m}\right)\right) * e^{\frac{\pi f_{nm} t_{nm}}{Q_{rms(n)}}}$ is a known quantity.

Taking ratio 1^{st} amplitude and m^{th} amplitude from n^{th} layer we will get relative reflection coefficient of n^{th} layer which can converted into absolute reflection coefficient.

$$A_{n1}/A_{nm} = (R_{n1}/R_{nm}) * (K_{n1}/K_{nm}) \quad (18)$$

Results and Discussion

Synthetic Data:

The synthetic data for a multi-layered earth has been generated using the reflectivity method with following model parameters

Vp(mt./s)	Vs(mt./s)	ρ(gm/cc)	Depth(mt.)	Int. Q
1480	0.001	1.03	1000	150
1^{st} interface				
1700	500	1.4	100	100
2^{nd} interface				
2200	900	1.6	200	200
3^{rd} interface				
1800	600	1.5	200	120

By adding 10% random noise, we have inverted the synthetic data. The estimated interval Q, and reflection coefficients at different offsets match reasonably with the true interval Q and reflection coefficients as shown below.

Qobs	Qest	%error
150	130.5382	12.97
100	91.343	8.65
200	167.298	16.35
120	124.352	3.63

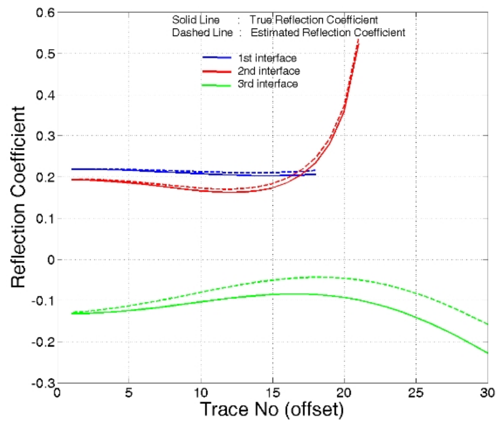

Figure 4: Comparison between true and reflection coefficients estimated from 10% noisy synthetic data.

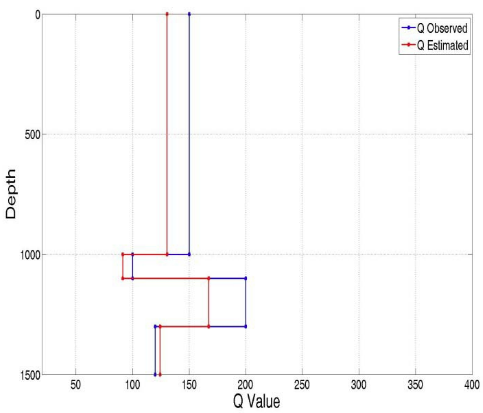

Figure 5: Comparison between true and estimated int. Q.

Real Data:

We have applied this approach on aprestack seismic gather of K G offshore and the results are shown below.

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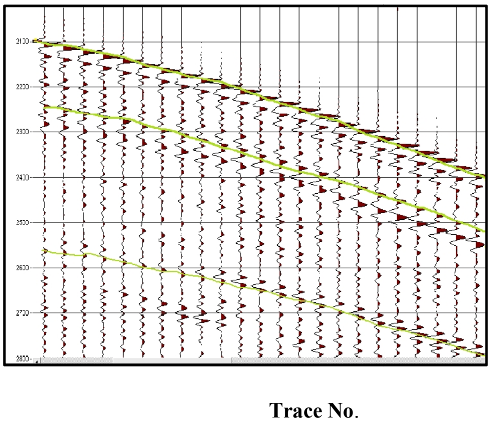

Figure 6: Prestack seismic gather of K G offshore.

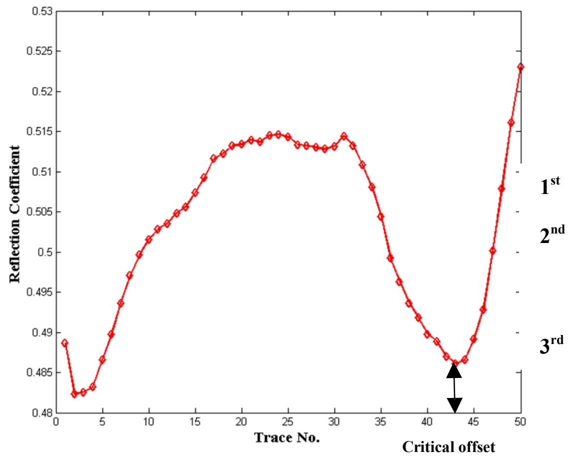

Figure 8: Estimated reflection coefficient of sea floor.

We have extracted amplitude and time from topmost three major reflectors including seafloor, and the data has been analyzed.

Amplitudes shows decreasing trend for sea floor and 3rd reflector and slight increasing trend for 2nd reflector (Fig. 7).

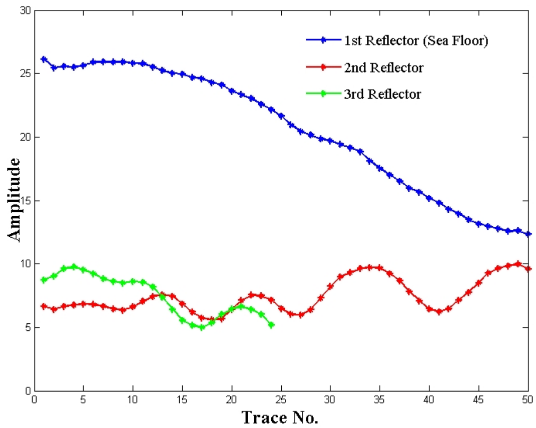

Figure 7: Comparison between extracted amplitudes of three reflector.

Estimated reflection coefficient for sea floor (Fig. 8) varies with offset from 0.47 to 0.53 and receiver no. 43 shows a critical reflection point. The ray parameter equation $\left({}^{v_1}/_{v_2} = \sin\theta_c\right)$ gives the 2nd layer P wave velocity 1872 mt/s taking the sea water P wave velocity as 1480 mt/s.

For 2nd layer the reflection coefficient shows a varying trend and 3rd layer it shows a decreasing trend (Fig. 9).

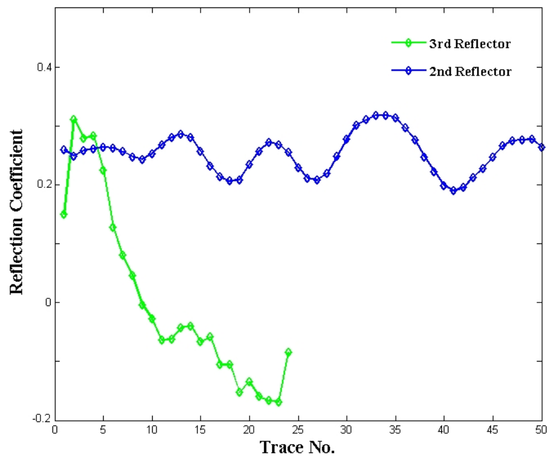

Figure 9: Estimated reflection coefficient of 2nd and 3rd Reflector.

Taking consideration of varying frequency the estimated Q value for sea water of 1500mt depth is 117. The 170 mt thick 2ndlayer have Q value 158, and for 3rd layer estimated Q value is 226.

Conclusions

We have presented a new approach for the estimation of interval seismic Q (attenuation) from amplitude versus offset reflection data for a multi-layered earth model. Besides Q, the approach can provide reflection coefficients at various offsets from different subsurface interfaces mainly from the primary reflection data. The validity of this layer stripping approach has been tested with noisy synthetic data. The result shows good match of reflection coefficient at shallower depth and near to middle offset. The TWT and amplitude data should be extracted very concisely for better result. The study does not include the horizontal anisotropy.

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