*J. Basic. Appl. Sci. Res.*, 2(1)48-53, 2012
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ISSN 2090-4304
**Journal of Basic and Applied Scientific Research**
*www.textroad.com*

# A Study of Relations between Velocity Ratio and Seismic Quality Factors Ratio

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## ABSTRACT

One of the most recent methods for estimation of quality factor (Q) is using vertical seismic profiling (VSP). In this research quality factor was determined by two different methods called amplitude decay and analytical signal. In regions that quality factor reduces, it is a good indication of gas channels. Also by using ($V_p/V_s$) ratio and comparing it with quality factor ratio or ($Q_p/Q_s$), gas or oil zones can be indicated. In this research the correlation equations between these two factors are studied. In the first step ($V_p/V_s$) changes in the well are determined, afterwards ($Q_p/Q_s$) changes were found by using VSP data.

**KEY WORDS:** Quality factor, Vertical seismic profiling, Amplitude decay, analytical signal, Correlation.

## 1. INTRODUCTION

The vertical seismic profiling (VSP) is a technique in which seismic signals generated at the surface of the earth are recorded by geophones at various depths in a borehole. The VSP has found a number of applications in the oil industry. VSP enables the acqusition of structural informations (e.g. position of reflectors and faults) and supports the interpretation of seismics by providing an identification of multiples. It also contributes to the characterization of lithological propeties such as acoustic impedance, the $V_p/V_s$ ratio fixed at depth and attenuation of medium [1]. One of the most important applications of near offset VSP is the estimation of quality factor (Q). Reduction of seismic wave's amplitude while transmitting through rock formations due to geometrical spreading, absorption and multiples.

Attenuation is related to (1/Q) and whenever attenuation is more, Q factor is less estimated from real data set. Characterization of different earth models can be accomplished by velocity, quality factor, amplitude decay and frequency content of the wave forms [2]. There are several methods for estimating quality factor (Q), those relating to time domain and some relating to frequency domain. Those related to time domain are amplitude decay, analytical signal, wavelet modeling, phase modeling, frequency modeling, rise-time modeling and pulse amplitude method. Also frequency domain methods are matching technique, spectral modeling and spectral ratio analysis [3].

The reminder of this paper is as follows: Time domain and frequency domain methods are summarized in section 2, then a brief review of amplitude decay and analytical signal methods are presented in 3. The results are given in section 4 and the paper is concluded in section 5.

## 2. Time domain and frequency domain methods

As a brief review of time domain methods, amplitude decay method is one of the simplest methods for computing Q based on the decay of amplitudes. The other method is Analytical signal which originates in complex trace analysis [4]. In wavelet modeling the travel time difference and the dispersion relation are used and then a reference signal at depth 1 is changed synthetically by changing Q so that an optimum approximation to an observed signal at depth 2 can be obtained [5]. Phase modeling is parallel to wavelet modeling; also in this model the instantaneous phases are modeled. Frequency modeling is sensitive to high frequencies and therefore it can be more sensitive to attenuation. In rise- time modeling it's noted that the basis is the dispersion of a travelling wavelet [6]. In pulse amplitude method both rise-time and the maximal amplitude of the first arrival is proportional to attenuation [7].

In frequency-domain methods, in matching technique the transfer function computation in the frequency domain is very critical [8] and Spectral modeling is the step for wavelet modeling [5] however, Spectral-ratio method is considered as the best method for estimating Q [9, 10].

These methods are considered in several studies, however [3] presents a comparison of different methods and determined the most practical ones.

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In recent years $V_p$, $V_s$ and their ratio ($V_p/V_s$) are used for the purpose of porosity estimation, lithology, sequence strata and fluid saturation in exploration seismology. The $V_p/V_s$ ratio is especially sensitive to pore fluid found in sedimentary rocks. In particular, the $V_p/V_s$ value is lower (10-20) percent for gas saturation than for liquid saturation analysis. $V_p/V_s$ used as a lithology indicator in shaly zones, sandstone and claystone. Also $Q_p/Q_s$ is used for distinguishing oil, gas and brine water saturation from data set [11].

In this research, Q factor is determined by the use of amplitude decay and signal analysis techniques. Then the correlation between $V_p/V_s$ and $Q_p/Q_s$ is found. In the following a brief review of Amplitude decay and Analytical signal method is established.

The time domain and frequency domain methods are illustrated in Fig 1.

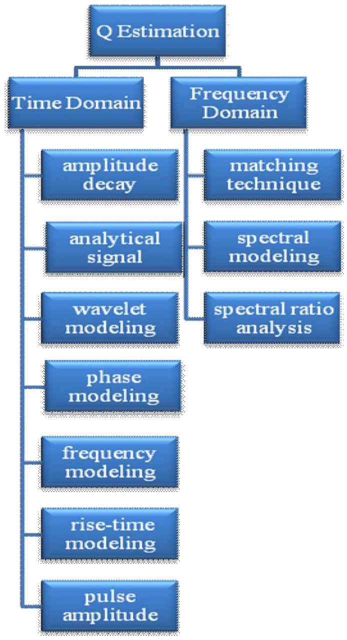


***Figure 1.*** *Time domain and frequency domain methods*

## 3. Brief review of Amplitude decay and Analytical signal method:

In this section, Amplitude decay and Analytical signal method are briefly reviewed. [3]

One of the simplest methods to compute Q is Amplitude decay method which is based on the decay of amplitudes. Using (1), the ratio of the amplitudes for different distances $x_1$ and $x_2$ (or times $t_1=x_1/c$ and $t_2=x_2/c$) yields:

$$Q = \frac{\omega \Delta x}{2c}\left\{\ln\left[\frac{a(x_1)}{a(x_2)}\right]\right\}^{-1} \qquad (1)$$

Where $f = \omega / 2\pi$ is considered as the dominant frequency. It should be noted that true amplitude recording is required in this method.

The second method is Analytical signal which originates in complex trace analysis. Based on [4, 11] we have:

$$u(t) = a(t)\cos[\Phi(t)] \qquad (2)$$

$$z(t) = a(t)\exp[i\Phi(t)] = u(t) + iv(t) \qquad (3)$$

Where z(t) is the analytical signal of u(t), v(t) is the orthogonal signal to u(t), and v(t) and u(t) are Hilbert transform pairs. a(t) is instantaneous amplitude and $\Phi$(t) is instantaneous phase.

And for the seismic quality factor we have:

$$\frac{1}{Q} = -2\frac{d}{d(\Delta x/c)}\left[\ln\frac{a(T)}{G}\right]\frac{1}{2\pi f(t)} \qquad (4)$$

Where Δx, C and G are the travel path in the medium, the phase velocity and the geometrical spreading, respectively and f(t) is instantaneous frequency. Also T is considered as the internal time. For the case of finite layers, the differential operator can be easily substituted by differences as:

$$\frac{1}{Q}=\frac{-2}{2\pi f(T)\Delta t}\Delta\left[\ln\frac{a(T)}{G}\right] \tag{5}$$

Or

$$\ln\left[\frac{a_2(T)}{a_1(T)}\right]=\ln\left[\frac{G_2}{G_1}\right]-\frac{\pi\Delta t}{Q}\frac{f_1(T)+f_2(T)}{2} \tag{6}$$

It should be emphasized that there are three methods for analysing equation (6) as Maximum method, Average method and linear approximation. In maximum method only the maximum of the instantaneous amplitudes are analysed, however in average method the samples of wavelets are seperately considered and the quality factor is yield based on the average of these estimations . In Linear approximation, Equation (4) is considered as a linear equation with intercept Ln ($G_2/G_1$) and slop ($\pi\Delta t/Q$). A Q-estimation which is given by least squares approximation has advantage that neither the true amplitudes nor the spreading factors need to be known [13].

In order to estimate $Q_P$, equations (1) and (6) are used and for the estimation of $Q_S$ we use:

$$Q_s/Q_p=4/3.(V_s/V_p)^2 \tag{7}$$

However, shear wave velocity is required for estimation of quality factor (Q). For the purpose of shear wave velocity estimation, the experimental equations of Castagna were used [12].

For saturated mudrocks:

$$V_S=0/862\times V_P-1/172 \tag{8}$$

And for dolomite:

$$V_S=0/583\times V_P-0/07776 \tag{9}$$

$V_p$ is easily obtained from exploration well's data.

However, $Q_p$ is estimated by the use of equations (1) and (4) and then $V_s$ is calculated from equations (8) and (9).

## 4. RESULTS

In this research, $Q_p$ and $Q_s$ are first calculated based on amplitude decay and analytical signal. By the use of amplitude decay method, Diagrams of $Q_p$ and $Q_s$ versus depth are shown in figure 2 also based on analytical signal method, diagrams of $Q_p$ and $Q_s$ versus depth are shown in figure 3. Castagna's experimental equations are used to estimate shear wave velocity.

Equation (9) is used for estimation of shear wave velocity in dolomite formations; this is due to the fact that dolomite was the dominant mineral in the studied zone. $Q_p/Q_s$ ratio and correlation between $V_p/V_s$ and $Q_p/Q_s$ was done in the well and then the Poisson's ratio is calculated and a similarity between Poisson's ratio and $V_p/V_s$ and $Q_p/Q_s$ ratios is found. In figure 4 diagrams of $V_p/V_s$ and $Q_p/Q_s$ in comparison with Poisson's ratio were shown. And finally in figure 5 the correlation between $V_p/V_s$ and $Q_p/Q_s$ is shown.

As its obvious form the aforementioned diagrams, Q values in the second method are assumed to be higher than the first method and they are more acceptable.

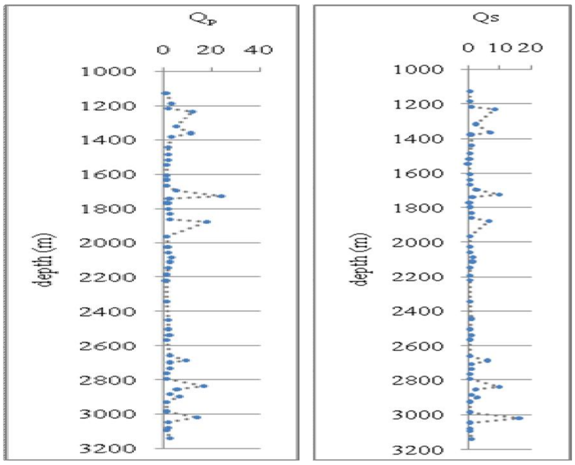


***Figure 2***. *Estimation of $Q_p$ and $Q_s$ according to shear wave velocity $Q_p$ and $Q_s$ in amplitude decay method*

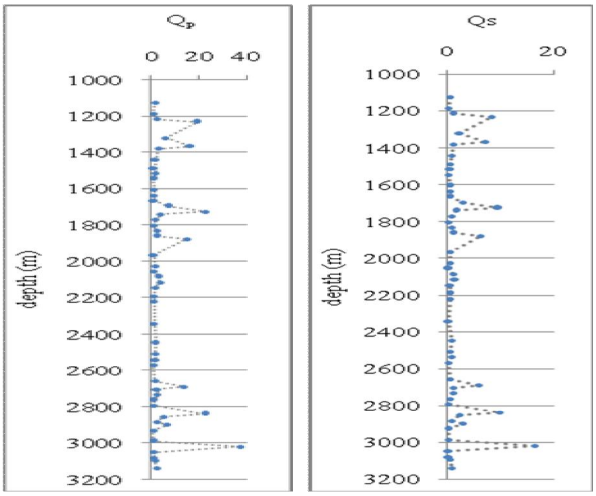


***Figure 3***. *Estimation of $Q_p$ and $Q_s$ according to shear wave velocity $Q_p$ and $Q_s$ in analytical signal method*

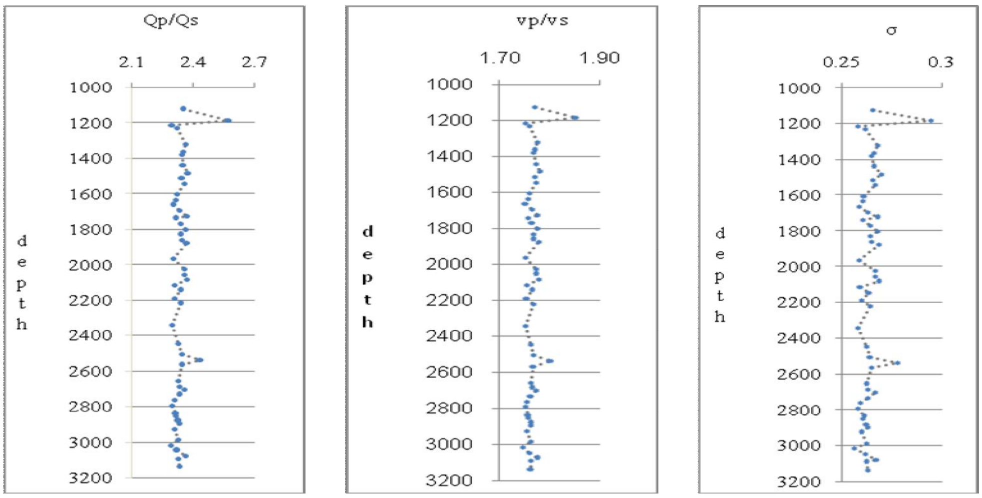


***Figure 4***. *Diagrams of $V_p/V_s$ and $Q_p/Q_s$ in comparison with Poisson's ratio*

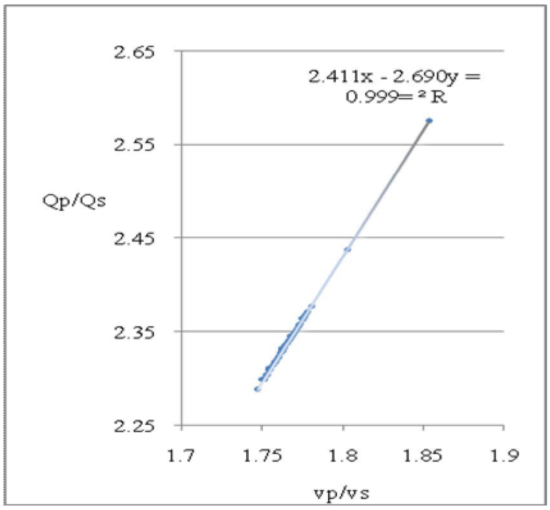


***Figure 5***. *Correlation between $V_p/V_s$ and $Q_p/Q_s$*

## 5. Conclusion

In this paper amplitude decay and analytical signal are studied as time domain methods to estimate the quality factor (Q). According to Q calculations in the studied area, there is a similarity between $Q_P$ and $Q_s$ in both methods. The Q values in analytical signal method in more depths are slightly more than that of in amplitude decay method. Whenever Q is reduced, attenuation is increased and it can be an indication of the hydro carbone existance. Similarity between $V_p/V_s$, $Q_p/Q_s$ and Poisson's ratio and also the good correlation between $V_p/V_s$ and $Q_p/Q_s$ are remarkable.

It can be concluded that in regions where $Vp/V_s$ and $Q_p/Q_s$ have similar trends, the Q value is more similar to the real data.

**ACKNOWLEDGEMENT**

The authors gratefully acknowledge the financial and other support of this research, provided by Islamic Azad University, Islamshahr Branch, Tehran, Iran.

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