# NEW APPROACH FOR SIMULTANEOUS ESTIMATION OF $Q_S$ AND $Q_C$

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In order to estimate attenuation of seismic waves, different methods have been introduced into seismology by using different part of seismograms (body wave, coda wave, surface wave, etc). In order to estimate the attenuation properties of media, several methods use coda waves (Single backscattering method, coda normalization method, etc). Based on the Single backscattering method (Aki and Chouet, 1975; Sato et al., 2012), the coda-Q ($Q_C$) can be determined by investigation the decay rate of seismogram's envelope at lapse times greater than twice the S-wave's arrival times. In order to estimate shear waves attenuation ($Q^{-1}_S$), the coda normalization method (Aki, 1980; Sato *et al.*, 2012) has been widely used. In this study we modified the coda normalized (MCNM) method to simultaneously estimate $Q_S$ and $Q_C$ parameter of media. By using radiative transfer theory (RTT) and Paasschens approximation (Paasschens, 1997) of radiative transfer equation (RTE), several synthetic seismogram's envelope has been generated at different hypocentral distances (10, 20 30, ..., 100, 110). By using synthetic seismograms the modified coda normalized method (MCNM) has been tested and modified. It has been seen in this study that for low noise synthetic envelopes, the MCNM method can precisely estimate $Q_S$ and $Q_C$ values. Based on the similarities found in the increase rate of normalized amplitude of S-waves and the decay rate of coda waves, the modified coda normalization method (MCNM) has been introduced to simultaneously estimate the coda-Q ($Q_C$) and quality factor of shear wave ($Q_S$) by using the following formula:

$$ln\left[\frac{A_S(f,r)G(r)}{A_C(f,t_c).t_c}\right] = -\frac{\pi f}{V_S Q_S(f)} r + \frac{\pi f}{Q_C} t_c + \text{const.} \quad (1)$$

Where $A_S$ is the maximum amplitude of direct S-waves at hypocentral distance of r, for a filtered seismogram with central frequency of f. $A_C$ is the average amplitude of coda wave at lapse time $t_c$ and G(r) is the geometrical spreading correction factor that consider to be $r^1$ for maximum amplitude of body waves at distances lower than 120 km. $V_S$ is the average velocity of S-waves which considered to be 3.5 km/s.

The equation has been used on all data paths and can be presented as equation:

$$D(f,r_{ij},t_c)=\begin{bmatrix}\left[\frac{A_S(f,r_{11})G(r_{11})}{A_C(f,t_1).t_1}\right]\\ \vdots \\ \left[\frac{A_S(f,r_{11})G(r_{11})}{A_C(f,t_C).t_C}\right]\\ \vdots \\ \left[\frac{A_S(f,r_{1j})G(r_{1j})}{A_C(f,t_C).t_C}\right]\\ \vdots \\ \left[\frac{A_S(f,r_{ij})G(r_{ij})}{A_C(f,t_C).t_C}\right]\end{bmatrix}=\begin{bmatrix}-\frac{\pi f r_{11}}{V_S} & \pi f t_1 & 1\\ & \ddots & \\ -\frac{\pi f r_{11}}{V_S} & \pi f t_C & 1\\ & \ddots & \\ -\frac{\pi f r_{1j}}{V_S} & \pi f t_C & 1\\ & \ddots & \\ -\frac{\pi f r_{ij}}{V_S} & \pi f t_C & 1\end{bmatrix}\begin{bmatrix}\frac{1}{Q_S}\\ \frac{1}{Q_C}\\ const.\end{bmatrix}\Longrightarrow D^{obs.}=Gm=D^{calc} \qquad (2)$$

In order to solve equation (2), bootstrap procedure and least square method have been used. In bootstrap method twenty sets of 20,000 initial values for the $Q_S$, $Q_C$, and constant values have been randomly generated with the following conditions:

$$10 < Q_C < 4000,\ Q_S < Q_C,\ 0 < \text{const.} < 10 \qquad (3)$$

In each set of 20,000 random model parameters, those with the lowest residual ($D^{obs}$-$D^{calc}$ =ε) has been selected. The mean and standard deviation of twenty input parameters with minimum residual have been calculated and considered as the results of Eq. (2). The results of bootstrap procedure seems to be comparable with the least square results ($[G^TG]^{-1}[G^TD^{obs.}]$. Finally the results of MCNM have been compared with those of traditional methods of Aki and Chouet (AC, 1975) and coda normalized method (CNM; Aki, 1980). As can find from Figure 1, MCNM has good correlation with those estimated using traditional methods of AC (1975) and CNM (1980).

Results of this study have proved that the newly introduced method, modified coda normalized method (MCND) can find precise results in low noise dataset.

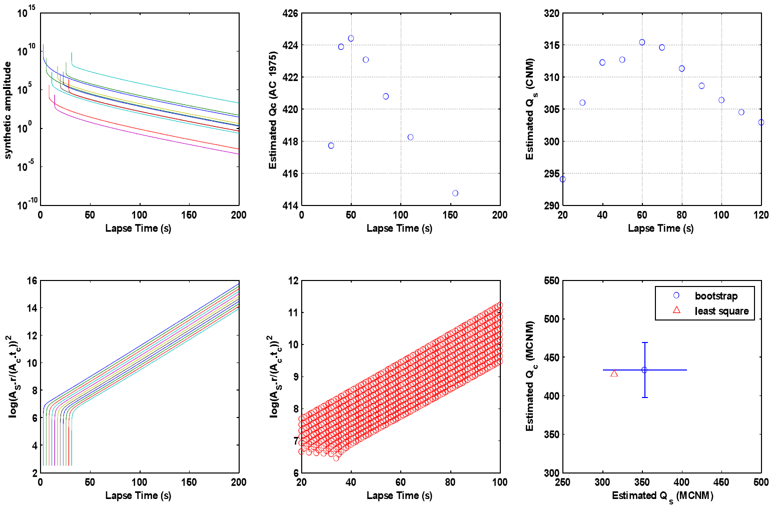


Figure 1. Synthetic envelopes calculated at different hypocentral distances (10, 20, 30 … 100, 110 km) is shown in top left. Estimated $Q_c$ values using AC (top center) and $Q_S$ values determined by CNM method (top right). The synthetic envelopes has been calculated at 3 Hz, for total quality factor of ($Q_t$ = 285, $Q_i$ = 398, $Q_{Sc}$ = 1003) derive from attenuation results of Alborz region (Farrokhi *et al.*, 2014). The procedure of determination of MCNM at different lapse times is shown in bottom left image for lapse times from 0 to 200 seconds. The input data of Eq. (2) is shown in bottom image. Comparison between results of MCNM method calculated using bootstrap and least square method is shown in bottom right image

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