Coda wave attenuation in Mara Rosa seismic zone – Goiás state, Brazil

Kellin Schmidt[1], Vinicius Ferreira[1], Lucas Vieira Barros[1] and Ronnie Quintero[2]
[1] Observatório Sismológico da Universidade de Brasília
[2] OVSICORI – Universidade Nacional da Costa Rica

Abstract

Small local earthquakes from aftershock sequence in Mara Rosa, Goiás state, Brazil were used to estimate the coda wave attenuation in the frequency band of 1 to 20 Hz. The time-domain coda-decay method of a single backscattering model is employed to estimate frequency dependence of quality factor (Qc) of coda waves modeled using $Qc = Q0f^{\eta}$, Q0 is the coda quality factor at a frequency of 1 Hz and η is the frequency parameter. Qc values have been computed at central frequencies and (band) of 1.5 (1-2), 3.0 (2-4), 6.0 (4-8), 9.0 (6-12), 12 (8-16) and 18 (12-24) Hz in the lapse time ranging from 5 to 25 sec in step of 5 seconds. It was determined the functional form $Qc = (10.78)\ f^{(1.84)}$.

Introduction

Seismic attenuation plays an important role in studies of the earth structure, from which useful information on medium properties can be inferred.

Determination of source parameters must take into account the proper attenuation characteristic of the wave path. Moreover, it is essential for seismic risk studies and seismic hazard assessment, and consequently for seismic risk mitigation.

In the last three decades, different studies in many parts of the world have used coda waves from small earthquakes to determine local attenuation properties of the crust (Barros et al. 2011; Dias and Souza 2004; Gupta et al. 1995). Coda waves from small local earthquakes are the superposition of backscattered body waves generated from numerous heterogeneities distributed randomly in the lithosphere (Aki 1969; Aki and Chouet 1975; Rautian and Khalturin 1978).

Therefore, the great variety of paths traveled by these scattered waves provides information concerning the average attenuation properties of the medium instead of just the characteristics of a particular path (Gupta et al. 1995). The attenuation of the seismic waves in the lithosphere is highly frequency dependent and is caused by the combination of two effects: scattering and anelastic attenuation (Havskov et al. 1989) and it is difficult to separate each other, since both have similar dependence on travel time or distance (Aki 1969; Havskov et al. 1989). Anelastic attenuation is strongly dependent on the tectonic environment, as demonstrated in many studies carried out in different places of the world (e.g., Havskov et al. 1989).

In the present paper, the single scaterring model has been used to study the coda Q attenuation in Mara Rosa, Goiás state, Brazil, using small local earthquakes following the mainshock of 5.0 mb (MMI VI) in October, 08 2010.

Seismicity of the area

The study area is located in Mara Rosa, in the north of Goiás state, Brazil, in the central portion of the Tocantins Province (Figure 1).

This structural Province is a region orogenetic Neoproterozoic, formed by the junction of the San Francisco and Amazon craton, and possibly a third continent, Paraná, covered by sedimentary rocks of the Paraná Basin and known individually as range Brasília, Araguaia and Paraguay; generating a system magmatic arc presenting one sequence with volcano-sedimentary rocks.

The crustal accretion event is of regional importance in the tectonic development of the Brasília Belt and Tocantins Province.

The recent seismicity observed in Mara Rosa started on October 4 of 2010, at 16h07m (local time), with an earthquake of magnitude 3.6 mD felt by the local population of Mara Rosa, Mutunópolis and Santa Tereza. However, other earthquakes had been recorded in this area in 1995, 1998, 2001 and 2006. Historical data, collected recently, realize that in 1962 an earthquake was felt in this area with intensity V Modified Mercalli Scale (MM).

The seismicity occurring in the States of Goiás, Tocantins and part of Mato Grosso has a preferential distribution to NE-SW direction and has been called Goiás-Tocantins seismic range (GO/TO-SR).

On October 8th of 2010, at 17h17m (local time) occurred the biggest earthquake ever detected in the GO/TO-SR, magnitude 5.0 mb and Imax = VI MM, felt even in Brasilia and Goiania located, respectively, 250 km and 300 km way from the epicenter. About 8 minutes later, another earthquake of magnitude 4.0 mb was detected. On October 19th of 2010 the Seismological Observatory (SIS) of the University of Brasília (UnB) started local studies, with the installation of nine-station seismographic network.

During eight months, from October 2010 to June of 2011, the seismic local network detected about 800 micro earthquakes.

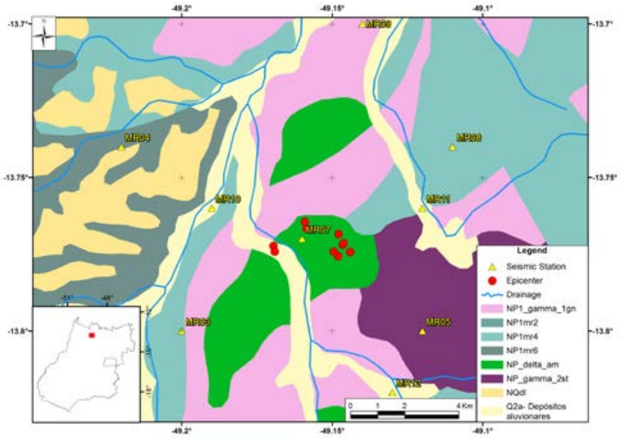

Figure 1 – Geological map of study area. Triangles denote seismic stations and red circles the epicenters.

Coda-Q method

Coda wave of local earthquakes can be explained as backscattered S-waves from lateral heterogeneities distributed uniformly in the lithosphere (Aki 1969; Aki and Chouet 1975). The scattering is produced by irregular topography, complex surface geology, and heterogeneous elastic properties of the rocks, faults, and cracks, which are more frequent near the surface and less in deep region (Kumar et al. 2005). This implies that the decay of coda wave amplitudes as a function of lapse time (time measured from the origin time) are similar to each other for different earthquakes in a given area, independently of the source and receiver locations (Biswas and Aki 1984). The decay of coda wave amplitude with lapse time, according to Aki (1969), at a particular frequency, is only due to energy attenuation and geometrical spreading but independent of earthquake source, path propagation, and site amplification. The attenuation of seismic waves is the sum of intrinsic and scattering attenuation, where, in the first case, the energy is converted in heat through anelastic absorption and in the second case it is redistributed through refraction, reflection, and diffraction at random discontinuities present in a homogeneous medium (Kumar et al. 2005). After the advent of coda wave theory by Aki and Chouet (1975) and Sato (1977), many studies (e.g., Herraiz and Espinosa 1987; Kumar et al. 2005; Kvamme and Havskov 1989; Rautian and Khalturin 1978) have shown that the coda Q factor increases with frequency through the relation:

$$Q(f) = Q_0\,(f/f_0)^{\eta} \qquad (1)$$

Where Q_0 is the quality factor in the reference frequency f0, usually 1 Hz, and η is the frequency parameter, which is close to unity. These parameters vary according to the heterogeneities of the medium, seismicity, tectonics, and geological features of each region (e.g., Jin and Aki 1988, 1989).

The single scattering model

Assuming single scattering from randomly distributed heterogeneities Aki and Chouet (1975) showed that the coda waves amplitude at frequency f and elapsed time from the origin, t, can be expressed as:

$$A(f, t) = S(f)\,t^{-v}\, e^{-\pi f t/Q(f).t} \qquad (2)$$

Where S(f), is the source function at a frequency f, v is the geometrical spreading parameter and Q(f) the coda wave attenuation quality factor (Qc), representing the attenuation of the medium. S(f) is considered a constant as it is independent of time and radiation pattern. The parameter v can assume the values 1.0 (for body wave scattering), 0.5 (for surface wave scattering), and 0.75 (for diffusive waves). As coda waves are mainly S to S backscattered waves (Aki 1981; Kvamme and Havskov 1989), the spreading parameter v = 1 is used in this study. However, as Aki and Chouet (1975) noted, the dependence of different envelopes on time are relatively insensitive to the value v.

Equation 2 is valid only if the coda window begins at least after twice the S wave propagation time, 2(Ts − To), to avoid the effects of direct S-wave in the coda window and to validate the assumption used in the model that receiver and source are very close (Rautian and Khalturin 1978). Or in other words, the scattering is not a function of the distance between receiver and source.

Taking the natural logarithm of Eq. 2, we obtain,

$$\ln A(f, t) + v \ln(t) = \ln(S(f)) - \pi f t/Q(f)$$

$$\ln[A(f, t)t] = k^{-bt}, \text{ for } v = 1 \qquad (3)$$

The above equation represents a straight line where b = π f/Qc and k = ln S(f).

Hence, Qc can be obtained from the slope of the linear regression of ln[A(f, t)*t] versus t, for a constant frequency. Then, in order to determine Qc, the seismogram is initially narrow-band-pass filtered at different central frequencies. Qc is determined for each frequency band and lapse time window, as will be seen in Section.

For this, the SEISAN package was used (Havskov and Ottomöller 2008).

Data selection and analysis

It was made a selection of only two events representatives of all the sequence, both detected by 8 stations simultaneously. The magnitudes of the events are 1,3

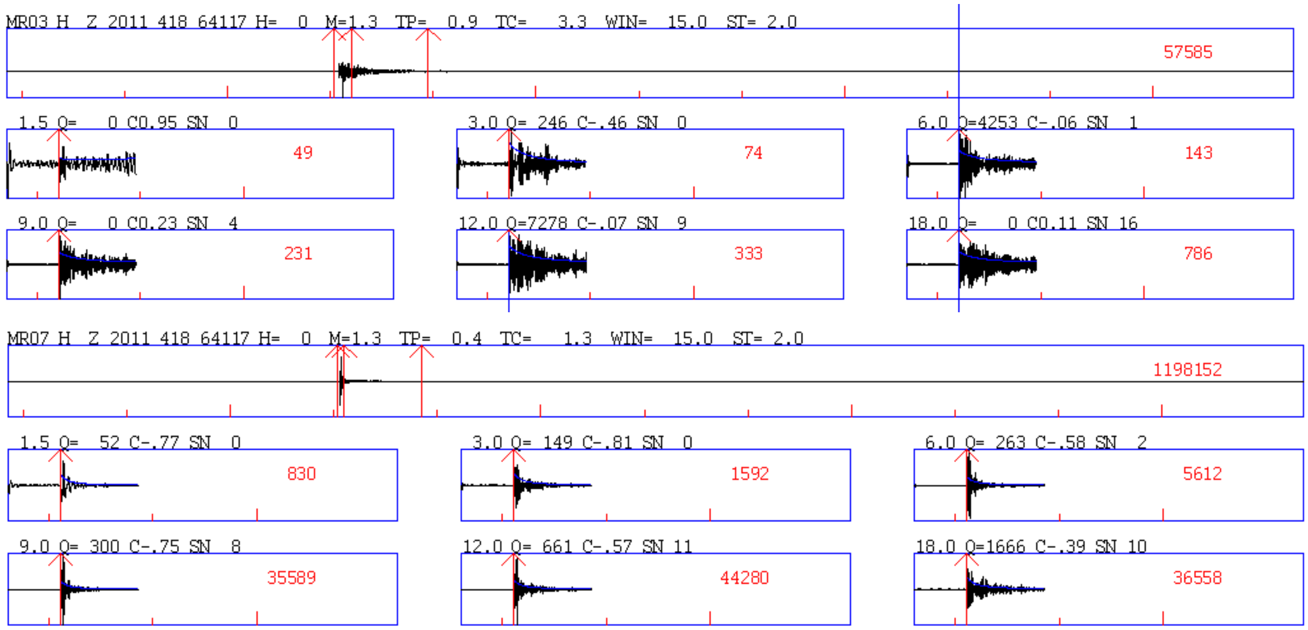

Figure 2 -. Examples of unfiltered and band-pass-filtered traces for two events recorded in different epicentral distances and depths. The first recorded by station MR03, and second recorded by the close station MR07, during 2011 seismic sequence. In each figure, the top trace is the original unfiltered signal where the three vertical lines indicate (from the left) origin time (T_o), window start ($2(T_s - T_o)$) and end of the coda window ($2(T_s - T_o) + WIN$).The abbreviations are: H = depth (km); M = coda magnitude; TP = P onset time; TC = start of coda window measures (in sec) from the origin; win = window length; start = start of coda window in terms of S travel time, always = $2(T_s - T_o)$; f = frequency in Hz; CO = correlation coefficient; and S/N = signal-to-noise. The fitted envelope of each filtered segment is shown as a decay curve for each central frequency.

Results

The table below presents a synthesis of all results gotten in this work.

Table 1 - Average Qc for each window length and central frequency.

N	Window length	1.5Hz (1-2) *Qc ± σ*	*N*	3.0Hz (2-4) *Qc ± σ*	*N*	6.0Hz (4-8) *Qc ± σ*	*N*	9.0Hz (6-12) *Qc ± σ*	*N*	12.0Hz (8-16) *Qc ± σ*	*N*	18.0Hz (12-24) *Qc ± σ*	*N*
1	5	12 ± 6	3	96 ± 78	2	59 ± 27	7	120 ± 80	8	291 ± 196	7	551 ± 83	4
2	10	0 ± 0	0	122 ± 30	3	215 ± 162	4	260 ± 144	4	338 ± 34	2	1.707 ± 349	3
3	15	0 ± 0	0	0 ± 0	0	368 ± 166	3	484 ± 421	2	660 ± 2	2	1.666 ± 0	1
4	20	0 ± 0	0	473 ± 0	1	521 ± 0	1	621 ± 0	1	1.571 ± 0	2	3.605 ± 0	1
5	25	0 ± 0	0	0 ± 0	0	0 ± 0	0	788 ± 0	1	1.397 ± 0	1	4.402 ± 620	7

N is number of Qc values used for the average and σ is the standard deviation. Quality factor and standard deviation for the Mara Rosa: the functional formula Qc = Q0 f^{η} for each window length is: (1) (25 ± 13) f (1.38 ± 0.23), (2) (48 ± 28) f (1.22 ± 0.39), (3) (75 ± 17) f (1.00 ± 0.35), (4) (120 ±53) f (1.13 ± 0.35), (5) (133 ± 75) f (2.45 ± 0.14)

The estimates of quality factor have been determined for the area representative datasets composed by two events detected by all stations simultaneously. The average Qc values for the region of Mara Rosa is: $Qc = (10.78)\, f^{(1.84)}$ according to Figure 3.

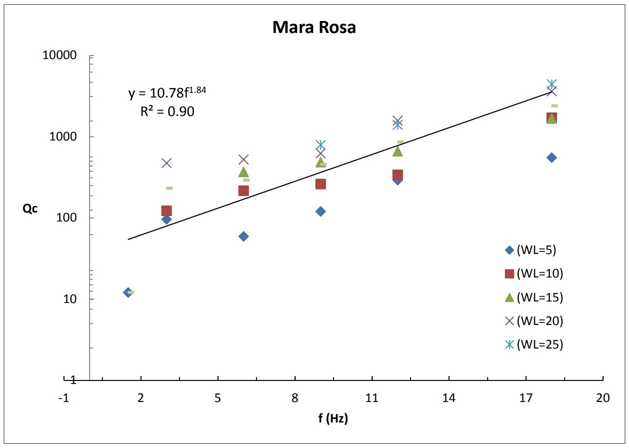

Figure 3 – Qc (f) for with fitted relationship Qc = Q0 f^{η} Data points refer to the five windows lengths (WL). Qc = $10.78f^{1.84}$. R^2 is the correlation coefficient.

To evaluate and compare the differences in the bahavier of the coda waves for different lapse times in terms of the quality factor in the reference frequency (Q0) and frequency parametter (η)it is presented in Fig. 4 for the region of Mara Rosa. (a) Quality factor (Qc) versus lapse time for six central frequencies analyzed, (b) Quality factor at a frequency of 1 Hz (Q0) and frequency parameter (η) versus lapse time.

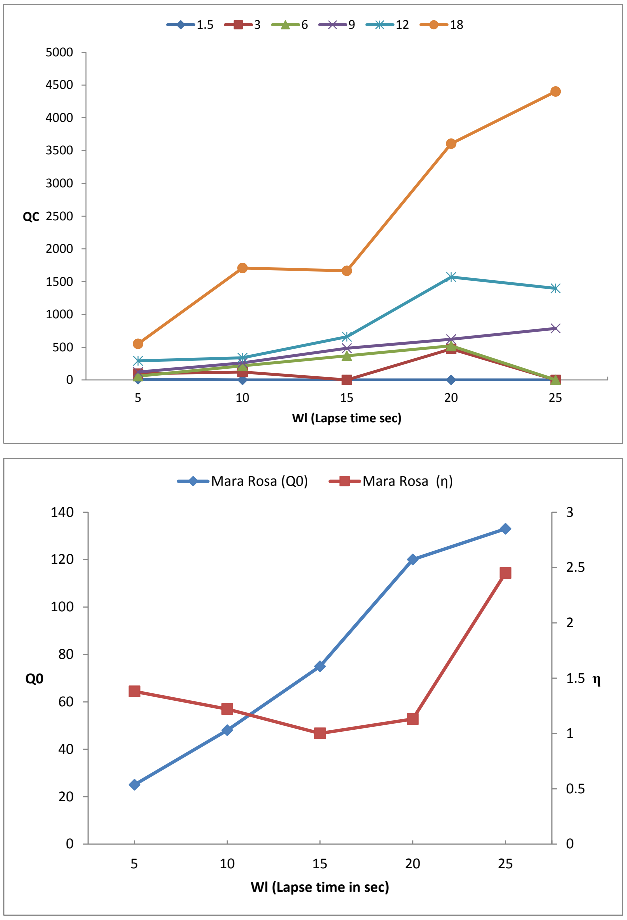

Figure 4 – Plot of average Qc, Q0 and η against lapse time (a) Average Qc with lapse time at different frequencies and (b) average Q0 and frequency parameter η against lapse time.

Discussion

The results of the average quality factor (Qc) for coda waves, estimated by linear regression for the Mara Rosa region in six frequencies bands are slightly different,

These results emphasize the conclusion that the behavior of coda waves reflects the type of geological environment in the subsurface.

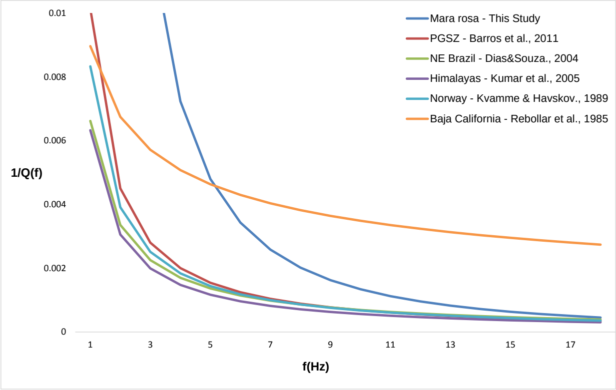

Figure 5 – Comparison of Qc^{-1} relationship obtained for Mara Rosa seismic zone (MRSZ) with other tectonic regions studied by others authors as indicated in the legend.

Fig. 5 shows the dependency of Qc-1 on frequency in Mara Rosa and in other regions according to the references on the Figure. The increase in values with the increase in frequency indicates the frequency dependence nature of Q estimates in region.

Conclusions

The e coda waves can be used to infer geological structures in subsurface, as the coda quality factor average values and frequency parameter demonstrated to be highly dependent on the geological environment.

So, it is possible to conclude that the application of coda Q method on local earthquakes, besides giving information on seismic wave energy attenuation and earthquake source parameters, can be used to infer useful information on earth structures

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